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Seabed classification from acoustic data collected during DRDC Atlantic/SACLANTCEN MAPLE trial

John A. Fawcett

Defence R&D Canada

Technical Memorandum

DRDC Atlantic TM 2002-141

January 2003

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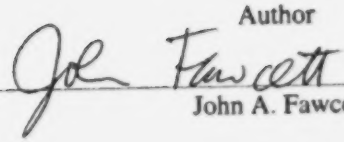

John A. Fawcett

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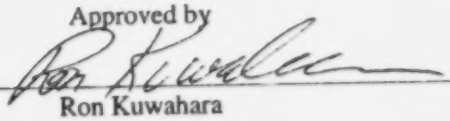

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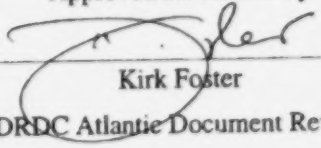

Kirk Foster

Head, DRDC Atlantic Document Review Panel

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Abstract

The properties of the seabed affect the amplitude and character of an echosounder or sidescan sonar return. Conversely, it is possible to use the statistical variation of these returns to segment the seabed into various regions – according to their acoustic characteristics. In this report we consider the returns from the SIMRAD echosounder (two different frequencies) on the CFAV Quest as well as the returns from the Klein 5500 sidescan sonar collected during the DRDC Atlantic/SACLANTCEN trial, MAPLE. Acoustic features are defined which allow us to segment the seabed into different acoustic regions for two different sites, Herring Cove, Halifax Harbour and St. Margaret's Bay. As well, some selected underwater photographs taken by SACLANTCEN and selected sidescan sonar images are presented from the 2 sites.

Résumé

Les propriétés du fond marin ont des effets sur l'amplitude et sur le caractère des échos produits par des échosondeurs ou des sonars à balayage latéral. Pour cette raison, il est possible d'utiliser la variation statistique des échos pour diviser le fond marin en diverses zones, en fonction de leurs propriétés acoustiques. Le présent rapport traite des échos de l'échosondeur Simrad (utilisant deux fréquences différentes) du NAFC Quest, de même que des échos du sonar à balayage latéral Klein 5500, qui ont été recueillies durant les essais MAPLE menés par RDDC Atlantique/SACLANTCEN. Des caractéristiques acoustiques ont été définies pour nous permettre de diviser le fond marin en zones acoustiques différentes à deux emplacements : Herring Cove dans le port d'Halifax et baie St. Margarets. Le rapport montre également, pour les deux emplacements, des photographies sous-marines choisies prises par SACLANTCEN et des images sélectionnées prises par le sonar à balayage latéral.

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Executive summary

Background:

The characterization of the seabed into areas of clutter, soft sediment, hard sediment, etc is important for mine-countermeasures as it can be used to predict areas of difficult minehunting and areas of possible mine burial. An efficient way of mapping out different seabed areas is by characterizing the acoustic response of acoustic sensors: echo sounders, sidescan sonars, etc and relating these characterizations to various seabed types. During the joint DRDC Atlantic/SACLANTCEN MAPLE trial of July, 2001 CFAV Quest and RV Alliance carried out surveys of Herring Cove (Halifax Harbour) and St. Margaret's Bay with a variety of acoustic sensors. This report considers utilizing two-frequency echosounder data for seabed classifications. In addition, sidescan sonar data is also considered. Underwater photographs and sidescan sonar images are presented to give an indication of the various seabed conditions.

Principal Results:

It is shown that consistent and reasonable acoustic characterizations can be obtained from the statistical analysis of echo sounder and sidescan sonar data.

Future Research:

It is hoped to apply the techniques discussed in this report to data collected in future sea trials in order to characterise the seabed materials which affect various MCM or UWW problems such as shadow/background contrast, clutter density, and burial probability.

Fawcett, John A.. 2002. Seabed classification from acoustic data collected during DRDC Atlantic/SACLANTCEN MAPLE trial. DRDC Atlantic TM 2002-141 DRDC Atlantic.

Sommaire

Contexte :

La caractérisation du fond marin en zones en fonction notamment du fouillis, des sédiments meubles ou des sédiments durs est importante dans la lutte contre les mines, car elle peut servir à déterminer les zones où la chasse aux mines est difficile et les zones où des mines peuvent être enfouies. Une méthode efficace pour établir une carte des zones ayant différents types de fond marin consiste à caractériser la réponse acoustique des capteurs acoustiques comme les échosondeurs et les sonars à balayage latéral, et à établir une relation entre ces caractérisations et les divers types de fond marin. Dans le cadre des essais MAPLE menés conjointement par RDDC Atlantique et SACLANTCEN en juillet 2001, le NAFC Quest et le RV Alliance ont effectué un relevé de Herring Cove (port d'Halifax) et de la baie St. Margarets à l'aide d'une variété de capteurs acoustiques. Ce rapport traite de l'utilisation de données provenant d'un échosondeur à deux fréquences pour la classification du fond marin. De plus, il examine également l'utilisation de données provenant d'un sonar à balayage latéral. Des photographies sous-marines et des images du sonar à balayage sont présentées pour donner une idée des diverses conditions du fond marin.

Principaux résultats :

Les recherches ont montré que l'analyse statistique des données provenant d'échosondeurs et de sonars à balayage latéral permettait d'obtenir des caractérisations uniformes et raisonnables.

Futures recherches :

On espère pouvoir appliquer les techniques présentées dans le rapport aux données qui seront recueillies lors de futurs essais en mer en vue de caractériser les matériaux du fond marin qui nuisent à la lutte contre les mines ou à la guerre sous-marine (p. ex. causent divers problèmes liés aux ombrages/au contraste avec l'arrière plan, à la densité du fouillis et à la probabilité d'enfouissement des mines).

Fawcett, John A. 2002. Seabed classification from acoustic data collected during DRDC Atlantic/SACLANTCEN MAPLE trial. RDDC Atlantique, TM 2002-141, RDDC Atlantique.

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INTRODUCTION

During July 2001 DRDC Atlantic and SACLANTCEN participated in a joint trial in the coastal waters near Halifax [1], MAPLE (Measuring the Acoustic Properties of the Littoral Environment). A variety of sonar data from the two ships, CFAV Quest (DRDC Atlantic) and RV Alliance (SACLANTCEN) were collected. This data included sidescan sonar data, multibeam sonar data, and echo sounder data. In addition, grab samples and photographs at selected sites were taken. In this paper, we analyze some of the sonar data collected at the Herring Cove and St. Margaret's Bay sites. In particular, we will investigate the use of the echo sounder and sidescan sonar data in characterizing the seabed.

In order to classify (or categorize) the seabed from the echosounder data, we compute features for the echo timeseries which tend to group the echo timeseries (when reduced to their feature values) into clusters. The centres of these clusters are determined by using a K-means clustering method. The concept of defining features and using some classification scheme is certainly not new and has been outlined by various authors (for example, [2-4]). In addition this type of concept is used in commercial packages such as QTC-View [3] and Roxann [4]. An analysis of these products and other seabed classification techniques can be found in Ref.5.

The Quest is fitted with a 3-frequency SIMRAD echosounder; during this trial, only the 38- and 120-kHz frequencies were used. In addition, the Klein 5500 sidescan sonar system was deployed from Quest during the trial and mosaics of the trial areas produced using the DRDC Atlantic (Sonar image processing system) SIPS system [6]. We will classify the seabed using the two echosounder frequencies individually and then by combining some of the features from each frequency to do a joint characterization. It is important to note that the individual frequencies will, in general, produce different regional characterizations of the seabed because the scattering mechanisms, depth of penetration into the sediment, etc are different in the 2 cases. In addition to the echosounder data there is, for much of the time, corresponding Klein 5500 sidescan sonar imagery. It is possible to define two-dimensional image features which can be used to characterize the seabed from the sidescan imagery [7]. This is beyond the scope of this report. However, in keeping with the spirit of analyzing the echo return we do investigate how the average intensity –versus- time curve varies over the survey and perform a site characterization using this quantity as well.

Pouliquen et al [8] from SACLANTCEN have also independently analyzed various portions of the data using a variety of classification techniques. Their seabed classifications appear to be quite consistent with those obtained in this report.

In the Appendix some underwater photos from various positions at the two sites are presented. These photographs show the wide variety of seabed conditions which were encountered during this trial, in terms of bottom type, shells, clutter, animal life, vegetation, etc. In addition some selected sidescan sonar images are presented, which also indicate the wide variety of features on the bottom.

Site Properties

In the area surveyed near Herring Cove the bottom is predominantly sand [9]. There are rocky shoals, notably Litchfield shoal and near the shoreline there may be some gravel. As the analysis and the photographs will show there is certainly variation within the sand: this variation can be due to factors such as the silt, gravel, grain size and biological content of the sand. The depth of much of the site away from the shore and shoals was 30-35m.

The St. Margaret's Bay Site probably has more variation than the Herring Cove site; in the MAPLE trial, only a small section (approx. 3.3 x 1.2 km box) of the bay was surveyed. Reference 1 displays the survey areas in the context of larger charts. Reference 10 indicates areas of: (1) Lahave Clay containing a large percentage of mud and giving low acoustic returns and areas of sandy mud and muddy sand; (2) Sable Island sand and gravel; (3) mostly muddy gravely sand; and, (4) areas of till (boulders) with pockets of fine sediment. There is also associated biologics with the sediments. There were fairly significant depth variations over the survey from about 20 m to 45 m, with the LaHave clay associated with the deeper parts of the survey.

Data Analysis

Echo sounder data

There are 2 types of data which will be used for bottom classification: the data from the SIMRAD echosounders (38- and 120-kHz data) mounted on CFAV Quest and the amplitude/cross-track range curves from the Klein 5500 sidescan sonar towed by CFAV Quest . In this section we analyze the echo sounder data obtained from the Herring Cove and St. Margaret's Bay sites. The full beamwidths for the 38- and 120-kHz echosounders are 7° and 10° respectively. Because the beams are spreading angularly, this means that the size of the Footprint on the bottom will depend upon the water depth. Using a representative depth of 35 m, these angular beamwidths translate into circles of 4.28 m and 6.12 m diameter for the 2 frequencies. It is interesting to note that the dimensions of the underwater photos shown in the Appendix are 90 cm (vertical) by 60 cm (horizontal). Thus a single timeseries from the echosounders is, in some sense, an average of the seabed characteristics over several photograph areas. The other type of data we consider are one-minute averaged normalization curves from the Klein 5500. This data corresponds to the average seabed characteristic on a scale of approximately 120 m (along track) x 150 m (across track).

Herring Cove

Below we show profiles from the 38- and 120-KHz systems for about 2 hours worth of data in the northern portion of Herring Cove and then for slightly over an hour for the southern portion of Herring Cove, Figures 1 and 2. The timeseries are averaged powers; they are sampled at 10 cm spacing for the first 500 points, the next 200 points are a zoom of the echo intensities, shifted so that the estimated first seabed reflection is always at point 550, with the seabed sampled at 2 cm. The data has a simple spherical spreading correction applied to it so that the power-dependence on the water depth should already be accounted for. In Figures 1 and 2, we effectively see an outline of the bathymetry (the upper line) with details of the echo structure below (the fluctuations between points 550 and 700). Visually, it can be seen that for the 2 frequencies the character of the echo changes over the run; for example, there are high scatter regions near rock outcrops (indicated by "bumps" in the bathymetry), more subtly, there are areas of higher amplitude, uniform return and areas with more extended return. For example, in the 38 kHz display of Fig. 2 there is a noticeable change at about the 4000 second mark. There are also changes for the 120 kHz display, although these are more subtle. We hope to construct "features" for classification purposes which capture some of this variation for the two frequencies.

In Fig. 3 a sidescan mosaic is shown with some reference points, which correspond to multiples of 500 seconds on the echo records (as well the ship track is indicated by a thin line). The sidescan surveys were performed in the two sections, but for the analysis below we combine the data from the 2 sets into one. Portions of the 2 runs overlap each other. The mosaic shows that there are areas of varying reflectivity; rocky shoals (Litchfield shoal is the large one) and the shoreline show high reflectivity. For the sidescan sonar this higher reflectivity is caused by the seabed material, but the slope of the bottom can also influence the apparent reflectivity. In Fig. 4 we have applied a threshold to the values of the mosaic and

from this it can be seen that there is an area corresponding to low reflectivity- towards the left in the northern section and in the centre in the southern section. Later in this report we will analyze the amplitude characteristics of the sidescan sonar returns in more detail.

We now wish to define some features which capture the variation of the echosounder data. The data will be the time series of Figures 1 and 2, from sample 550 to 700, that is the highly sampled portion of the time series starting with the first seabed reflected energy. The data will be averaged over 10 pings and the features defined for these averaged pings. The first feature for the 38-kHz echo is the level of the maximum return, expressed in dB (although the average is performed in linear space), the second feature is the ratio of the mean amplitude in the first 20 bins of the return from the seabed (in the zoom portion) to the mean value in the next 20. This is a measure of the "compactness" of the return. The third feature is the last index where there is a return of 0.1 the value of the maximum return. This was found to be a useful feature for distinguishing rocky areas. For the 120 kHz echos we only use 2 features, the maximum amplitude in dB and the ratio of the mean amplitude in the first 60 bins of the return to the mean amplitude of the subsequent 60 values.

The features in all cases are then smoothed over a running average of 11 feature values and then demeaned and normalized by their standard deviations. One issue we are ignoring somewhat is that of water depth. Some of the scattering features are affected by the water depth; for example, there will be more beam-spreading for deeper water and hence one would expect a longer amount of scattering in the time domain. The signal has had a time-varying gain applied to account for spherical spreading so that the peak levels (assuming a specular type reflection) are somewhat compensated. In general, one should also apply some sort of stretching to the return to try to account for the spreading of the beam; we have not done this here, but as can be seen from the record, the amount of depth variation, apart from the shoals, is not very large in this example. In Figure 5 the variation of the feature sets over time are shown for the two frequencies.

These features are input into a K-means clustering algorithm, where we have chosen to seek 5 classes. In Figures 6a and 6b we show the resulting clustering in feature space for the two frequencies. In both cases, the class assignments seem very reasonable. One concept that is important to note is the ambiguity between different scattering mechanisms. For example, a hard but somewhat rough surface could sometimes yield the same amplitude of reflection as a soft bottom with significant volume scattering (shells, worms holes) etc. In Fig. 6b, the cluster plot for 120 kHz, it is clear that there are 2 classes which have similar maximum amplitudes of returns but are distinguished by how diffuse their return is – this is likely a case of a harder but rougher bottom giving the same maximum amplitude as a softer but smoother bottom; however, the second feature which is a measure of the ratio of the power of the first portion of the return to the second portion, distinguishes them. For the 38-kHz cluster plot, the clusters are approximately distributed along a single curve in feature space. For the 120 kHz cluster plot there is more two-dimensional variation of the clusters. We also take the first two features for the 38-kHz sounder with the 2 features for the 120-kHz sounder and combine them as a four feature set. We can only display 3 of these features so in Fig. 6c we show the class assignments for the first three features (even though the clustering was done with respect to 4). There seems to be a significant three-dimensional character to the clusters.

Finally by using the GPS positions associated with each ping we can superimpose the classes (colour-coded) on the sidescan mosaic, Figure 7. The results from the three sets of data, 38 kHz, 120 kHz and combined are shown. The two frequencies map out the regions somewhat differently, this is not surprising because of the different scattering mechanisms. The results are overall encouraging. For the three different cases, the segmentations are contiguous (i.e., there is not a large amount of rapid variation between the classes) and in the case that there is overlap between diferent portions of the survey, the classifications are usually the same or from a "neighbouring" class.

All 3 segmentations are reasonable. There are some differences between the 38-kHz and 120-kHz results. This is to be expected as the physical scattering mechanisms, the depth of penetration of the acoustic energy into the sediment, etc are different for the 2 frequencies. It is difficult to make a definitive interpretation of the segmentation in terms of actual bottom type, but we can try to make some general statements. For example, let us consider the segmentation from the combined set of features (Fig. 7c). There is a region to the north of Litchfield shoal (dark blue) where we hypothesize fairly compact sand giving a relatively high and compact return. The red region has weaker and more diffuse returns and this we take to correspond to a muddier, siltier sand with perhaps more biologics. This can be seen in the photographs which seem to show a rather soft bottom with many starfish. The yellow class is intermediate between the "blue" and "red" classes. The green and cyan classes indicate more gravel and rock content. There is a region of "red" which appears to be close to the shoreline. This region may correspond to the soft bottom type with biologics or possibly it is a gravely area which produces much the same acoustic response. As discussed previously it is possible for different bottom types to produce much the same acoustic response. In the cluster plots, these would correspond to the points which are near the boundaries of their class. However, in general the segmentation has produced a contiguous, interpretable map which seems to agree nicely with the sidescan imagery.

Some selected sidescan sonar images and underwater photographs (R.V. Alliance) are presented in the Appendix.

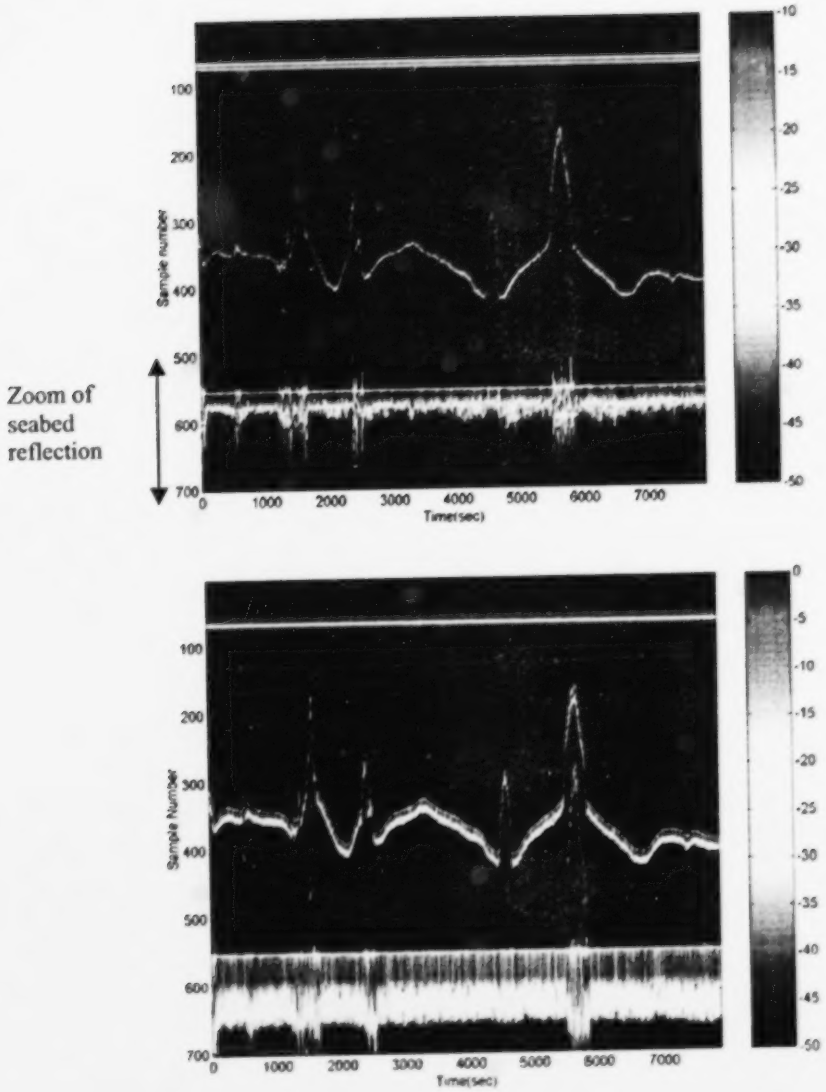


Figure 1 Echo sounder data from Herring Cove (north), top panel is 38 kHz and bottom panel is 120 kHz. The first 500 samples show the initial ping, the water column and the reflection from the seabed. The last 200 samples are a higher resolution time sampling of the echo near the time of the seabed reflection. The data is shifted so that the best estimate of the initial seabed reflection for each ping is always at sample 550. Thus, in this portion of the record the seabed reflections are approximately flat as a function of the ping.

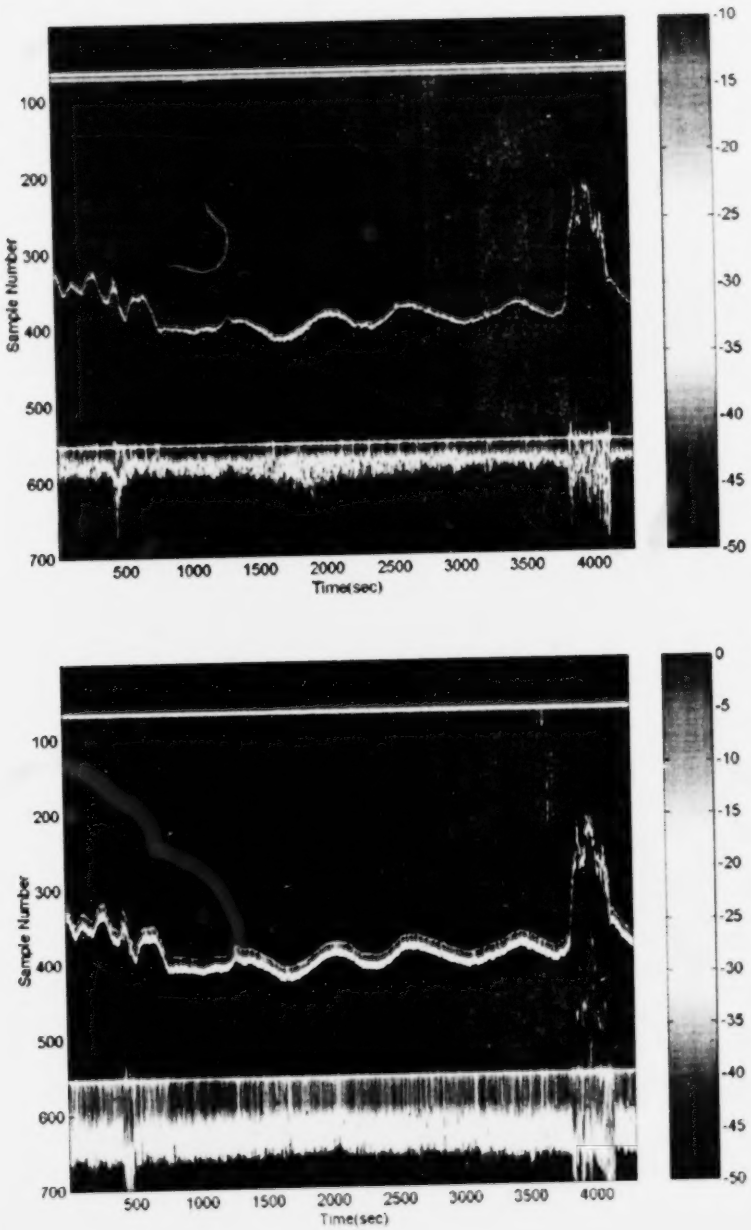


Figure 2 Echo sounder data - Herring Cove (south), top panel is 38 kHz and bottom panel is 120 kHz.

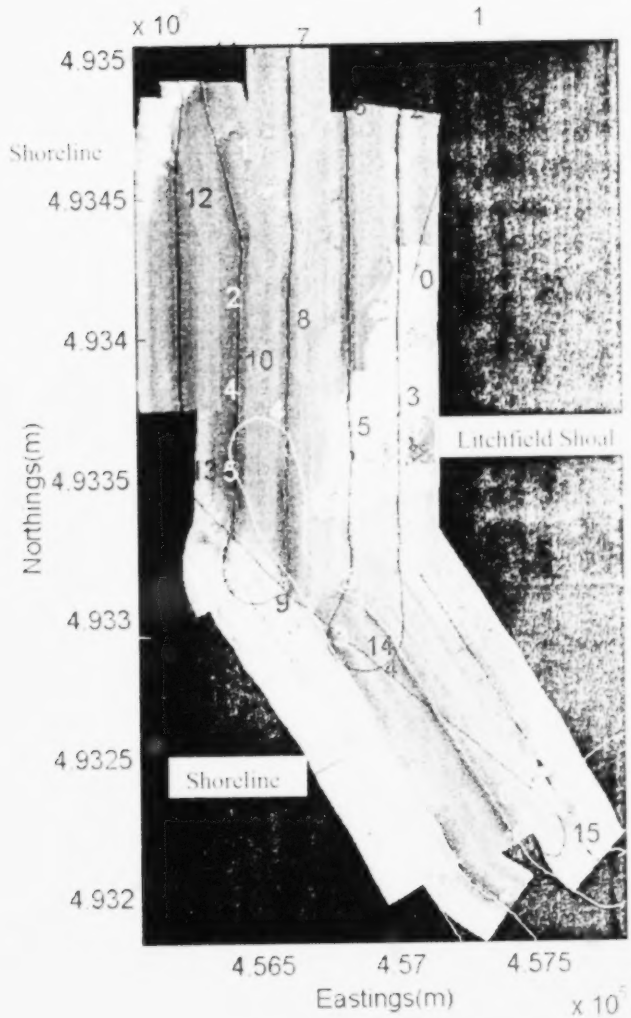
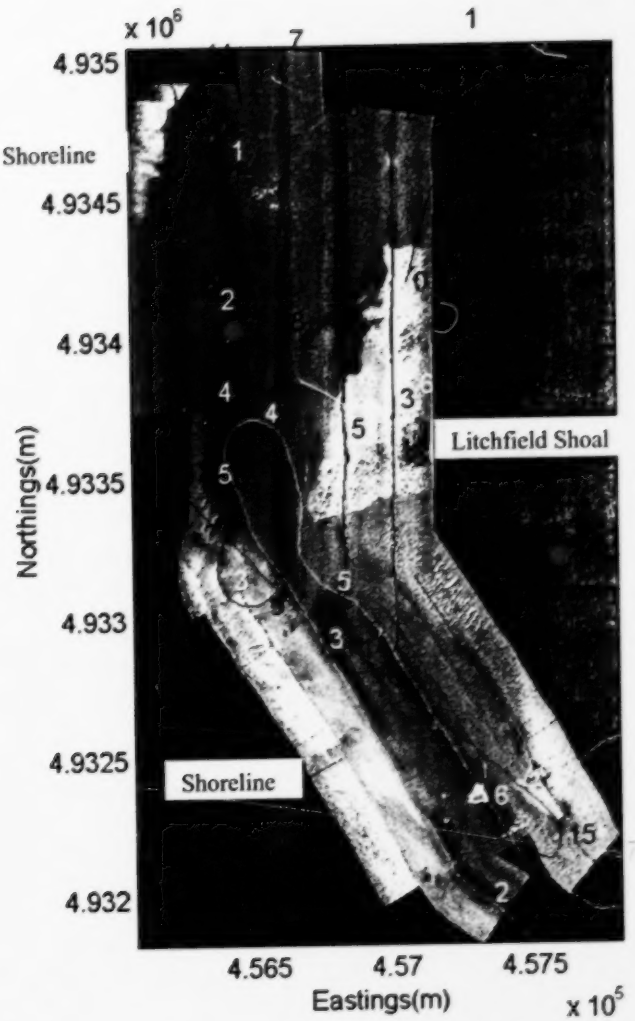


Figure 3 Sidescan sonar mosaic of Herring Cove area. The blue numbers indicate the ship position at multiples of 500 points in the echosounder record of Figs. 1; the green numbers, for the echosounder records of Fig. 2; the yellow numbers are the positions of the underwater photographs. The thin lines show the ship's track during the first part (blue) and the second part (green) of the survey



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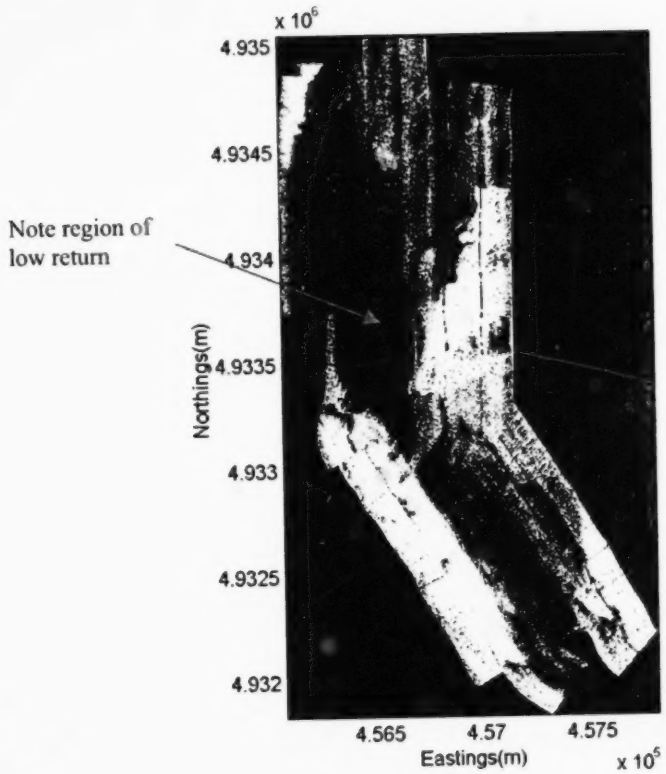


Figure 4 The sidescan mosaic with values above a threshold shown as white. Different regions can be visually seen. An area of low amplitude can be seen in north Herring Cove in the upper left region and to a certain extent in the middle of the southern region. There also regions of high brightness and moderate brightness.

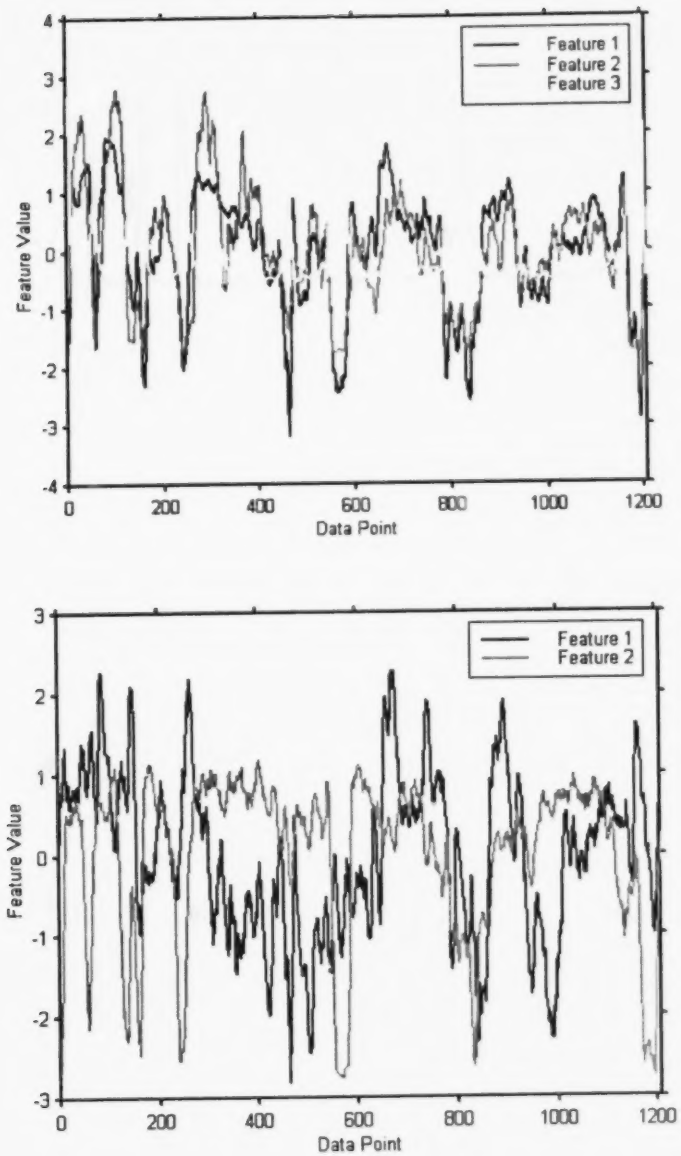


Figure 5 Variation of feature values for the echo sounder record for the entire Herring Cove data set, the top panel is for 38 kHz and bottom panel for 120 kHz.

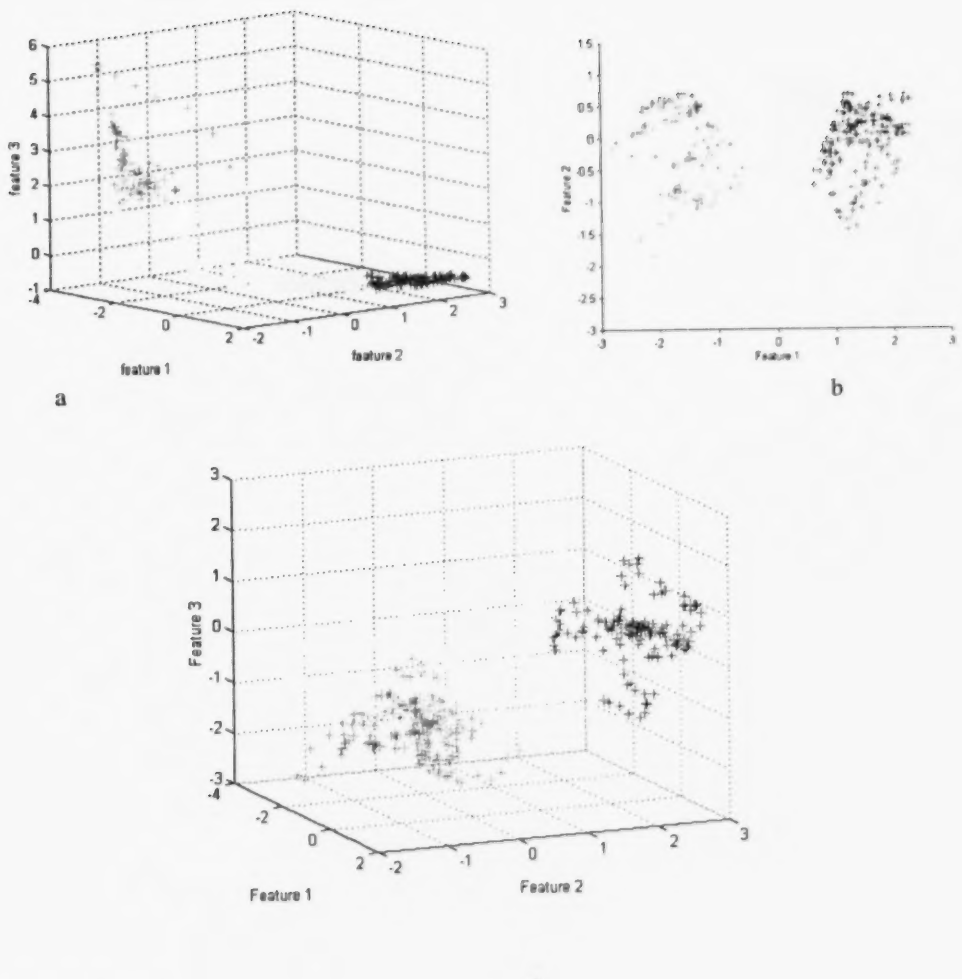


Figure 6 Results of clustering using a K-means algorithm; (a) 3 features clustering for 38 kHz, (b) 2-features clustering for 120 kHz, (c) 4 features clustering (plotted only as a function of the first 3 features) for combined 38/120 kHz.

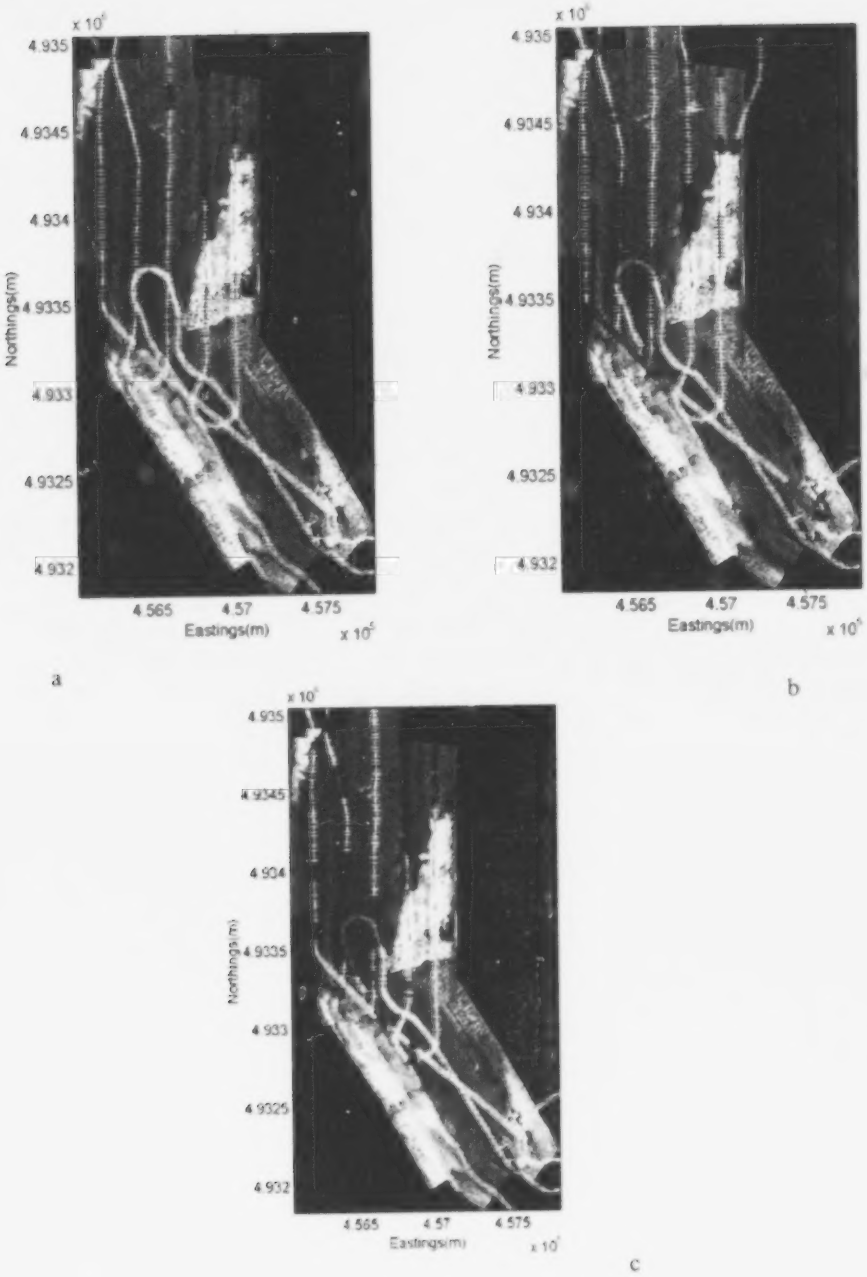


Figure 7 Resulting geographical segmentation using the cluster results from Figure 6 for: (a) 38 kHz data, (b) 120 kHz data, and (c) combined frequencies.

St. Margaret's Bay

We now repeat much of the analysis of the Herring Cove data for the data from St. Margaret's Bay. A comparison of the St. Margaret's Bay 38-kHz echosounder data with the corresponding Herring Cove data shows significant differences in the duration of the acoustic return. It is believed this is because the transmit pulse characteristics were changed. The echo amplitude shows significant variation and there is also some variation in the length of the echo, although, perhaps, not as much as for the Herring Cove data. The very weak returns correspond to the areas of LaHave clay. The echo records for the 2 runs are shown in Figs. 8 and 9. The locations of every 1000th ping is shown in Fig. 10 on top of the sidescan sonar mosaic – Run 1 is indicated in blue and Run 2 in green. The numbered locations of the underwater photos shown in the Appendix are shown in yellow.

From the echosounder data, the same type of features as for Herring Cove are defined: for the 38-kHz data, 3 features are used, the maximum value in dB, the ratio of the mean value in the first 50 bins to that of the second 50 bins, and the length to the last value of the signal exceeding 0.1 of the maximum value. For the 120-kHz data, only the first 2 features are used, where the second feature is now the ratio of the mean of the first 60 bins to the second 60 bins. Finally, we combine the first 2 features for each frequency to form a combined set. The sets of features for the 2 frequencies are shown in Figs. 10 and 11. The clustering algorithm is then applied to these features. The resulting clusters for the 38 kHz, 120 kHz, and combined frequencies are shown in Fig. 13. Structurally, these clusters are somewhat similar to the Herring Cove ones: the 38-kHz case is basically a linear, curved distribution, the 120 kHz has significant two-dimensional variation and the combined case (the clusters are only shown as a function of 3 of the four dimensions) shows three-dimensional structure. Unlike the Herring Cove case where the bathymetric variation was small away from the shoreline and shoals, this data set had significant bathymetric variation which can be observed in the upper part of the echosounder data. One can attempt to define the features so as to minimize the effect of the water depth (see, for example, [5] for a discussion of this) – we did not do this here, the resulting area segmentations seemed reasonable and not particularly correlated with water depth (there is, of course, some natural correlation with water depth, for example, the low amplitude returns of the LaHave clay are colocated with the deep parts of the bay). The resulting segmentations are overlaid on top of the sidescan sonar mosaic in Fig. 13. As can be seen, the segmentations are quite contiguous and consistent among the 3 sets of features. For example, the combined frequency segmentation (Fig. 13c) shows 4 major regions. There is the dark blue region, corresponding to the deep part of the survey with significant LaHave clay. This is a region of low returns at both frequencies. It is interesting to note that the altimeter on the Klein 5500 towfish lost lock many times over this bottom (and this is the only time this has happened in the author's experience). There are broad regions of red and cyan which differ primarily in the strength of the 120-kHz return. As discussed in the analysis of the Herring Cove, it is difficult to give a definite interpretation of the acoustic classes in terms of actual seabed types. A detailed examination of the sidescan sonar mosaic seems to indicate that the "cyan" regions correlate well with areas containing many boulders. Finally, in the western portion of the survey, there is generally a mixture of the red, yellow, and green classes. The fact that there are several small areas of these different classes in this area is consistent with the photographs in the Appendix, Figs. 34-39, which indicate a wide variety of bottom conditions in the shallower regions.

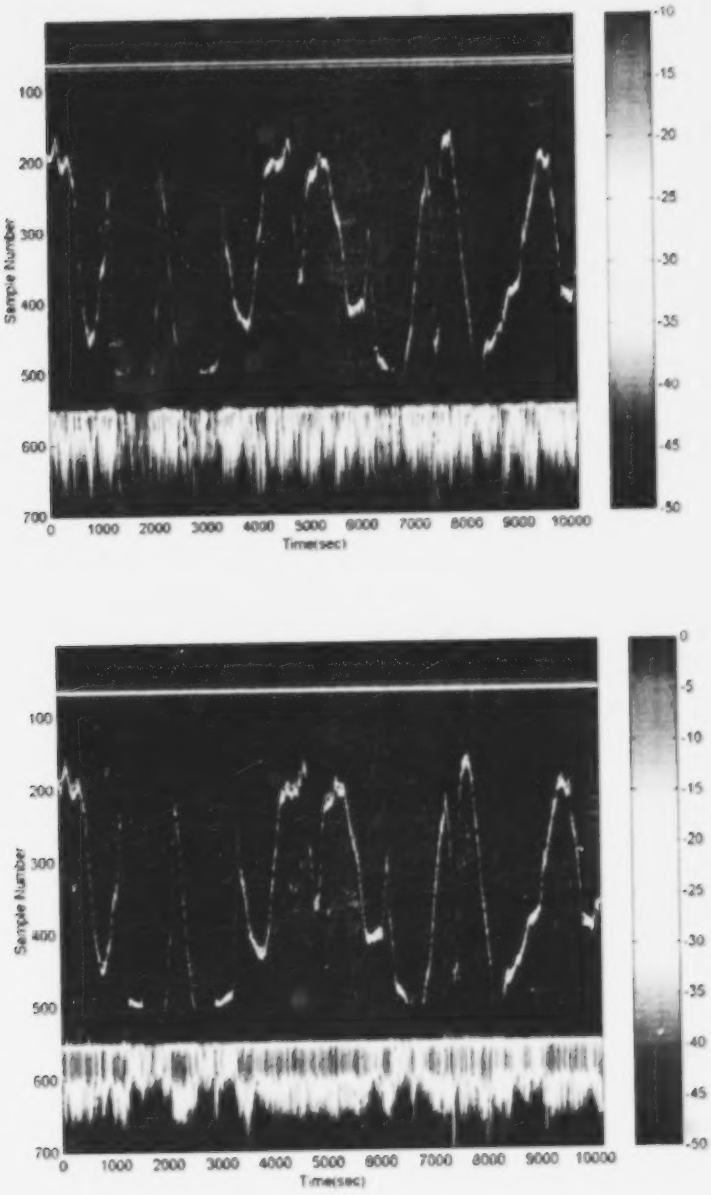


Figure 8 Echo sounder data – St. Margaret's Bay - Run 1 - top panel is 38 kHz and second panel is 120 kHz. The arrangement of the data is the same as for Herring Cove, the first 500 time samples show the ping history, the last 200 points are a higher resolution sampling of the signal near the time of the first seabed reflection, which is at sample 550 for all pings.

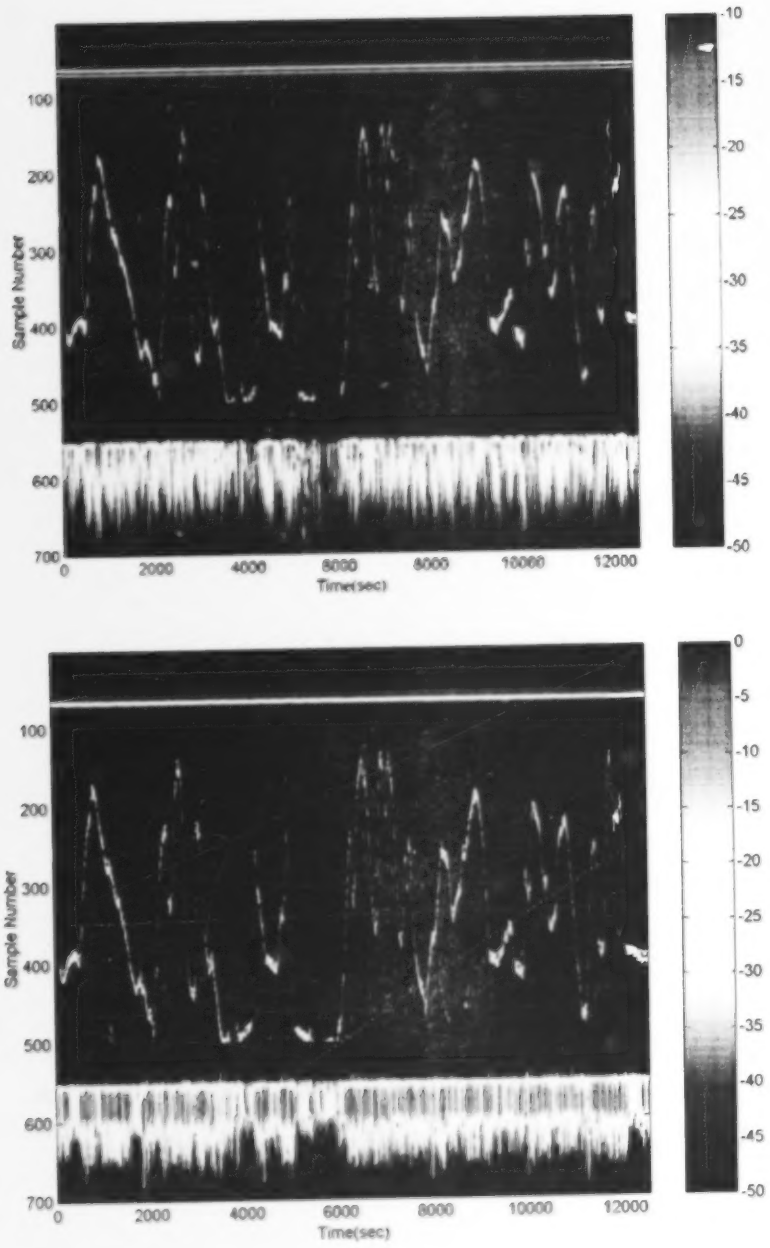


Figure 9 Echo sounder data – St. Margaret's Bay - Run 2 - top panel is 38 kHz and bottom panel is 120 kHz.

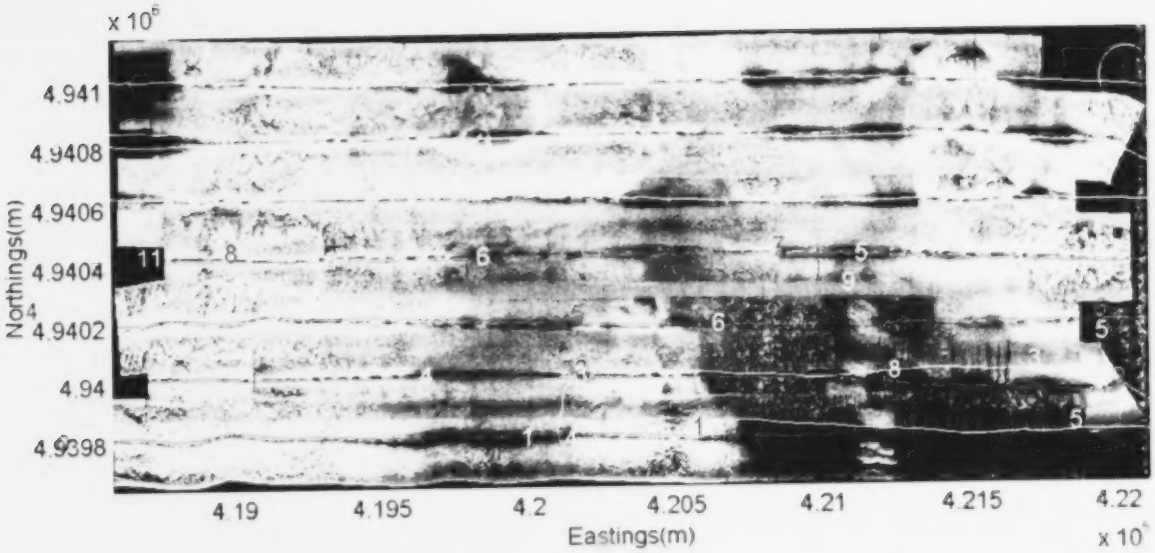


Figure 10 Sidescan sonar mosaic showing the locations of every 1000th ping for Run 1 (blue), Run 2 (green) and locations of " vater photographs of the Appendix (yellow) and screen grabs for sidescan sonar im. ,-yan). The ship's tracks are indicated by blue (first portion of the survey) and green (second portion of the survey).

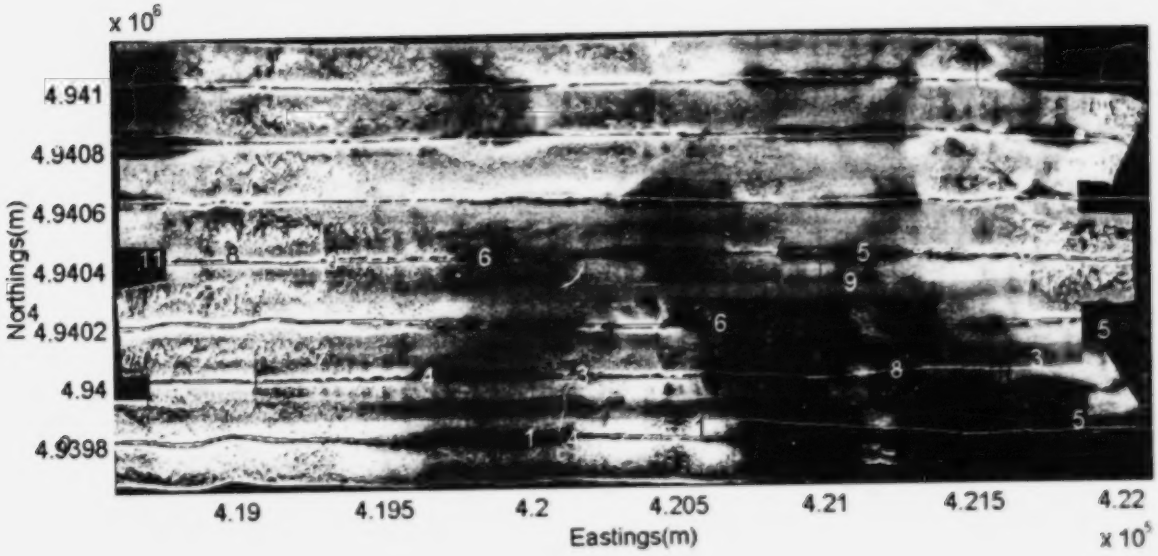


Figure 10 Sidescan sonar mosaic showing the locations of every 1000th ping for Run 1 (blue), Run 2 (green) and locations of the underwater photographs of the Appendix (yellow) and screen grabs for sidescan sonar images (cyan). The ship's tracks are indicated by blue (first portion of the survey) and green (second portion of the survey).

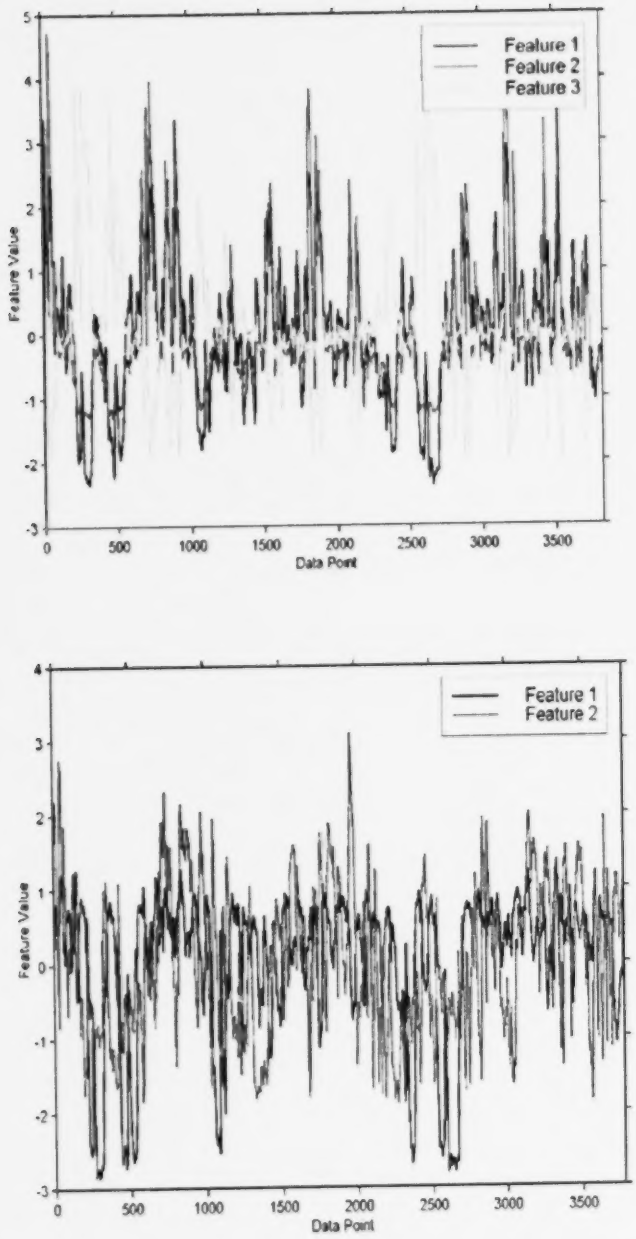


Figure 11 Normalized features for the 38-kHz and 120-kHz echosounders.

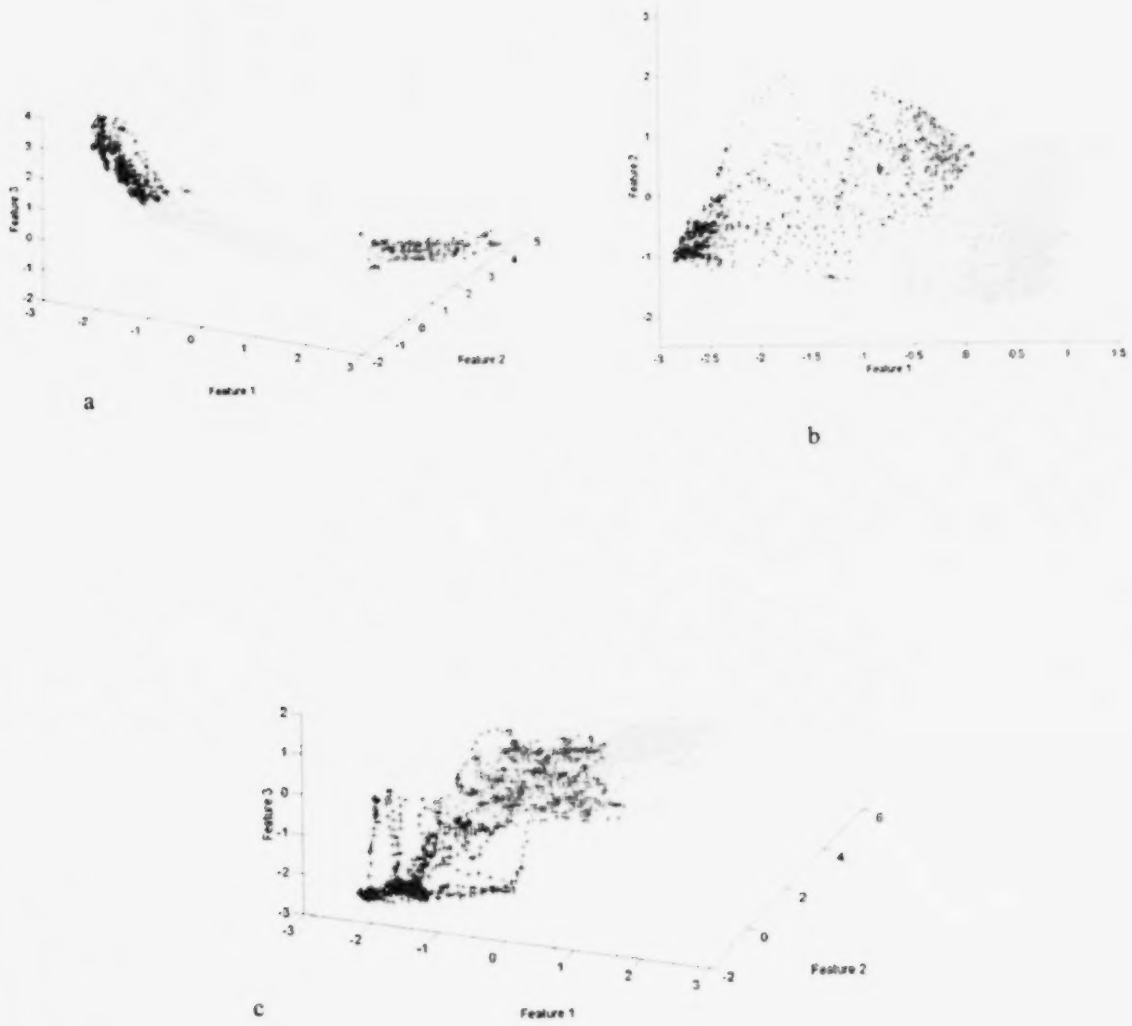
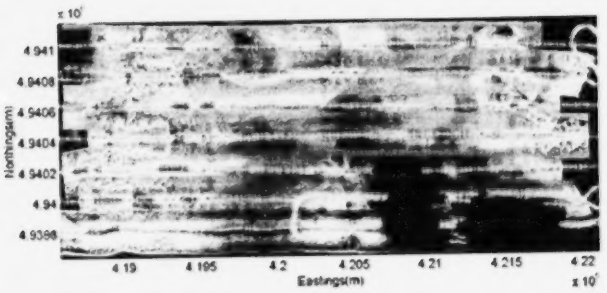
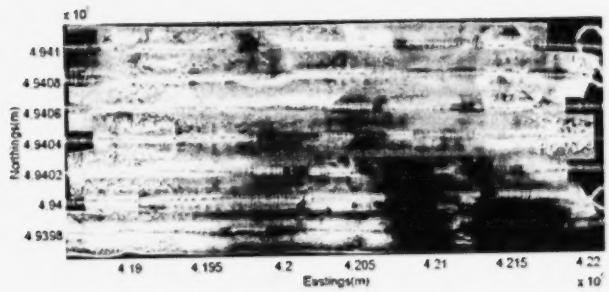


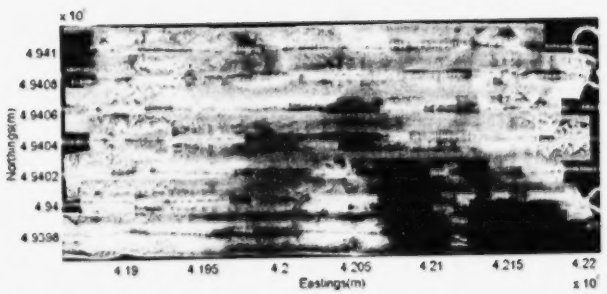
Figure 12 Cluster plots for St. Margaret's Bay for: (a) 38 kHz, (b) 120 kHz and (c) combined features set.



a



b



c

Figure 13 Geographical segmentations for St. Margaret's Bay for: (a) 38-kHz data, (b) 120-kHz data and (c) combined set of features.

Analysis of sidescan sonar amplitude/cross-track range curves

The sidescan sonar is typically towed 10-15 metres above the seabed. The vertical beamwidth of this sonar is large and the horizontal beamwidth small. For the Klein 5500 sidescan sonar and for the settings of the trial, 5 beams (each side) are formed with 20-cm along-track resolution (for surveys with minelike objects the 10-cm resolution was usually used). Due to the tow speed some of these beams are redundant, that is they overlap beams from the previous ping, but in the following analysis all the beams will be used. The initial energy scattered back to the sonar is from normal incident energy but as the pulse propagates this angle of incidence quickly decreases until the grazing angle of the incident energy is very small. There are several different mechanisms influencing the amplitude of the backscattered signal; there is the angle of incidence which decreases quickly after the initial return, there is geometrical spreading of the incident pulse, there is the attenuation of the seawater, and there is the actual scattering characteristics of the seabed which is what we are interested in. In the analysis of sidescan sonar data, one often computes a mean amplitude/cross-range or amplitude/angle and the data is normalized by this curve. In this way the bulk geometrical dependencies of the data can be removed. This was done in the production of the sidescan mosaics which are used in this report and in [1]. This concept of using the amplitude curves for classification has been applied to a multibeam bathymetric sonar in Ref. 11. It is also possible to use image analysis to segment sidescan sonar imagery [7]. Here, we attempt to use features of the amplitude curves to distinguish different seabed types. It is clear from the sidescan mosaics already presented, that the variation of the sidescan amplitude yields valuable information about the seabed bottom.

To compute the normalization curves, the data is read in from the individual Klein files. For each ping record (port and starboard) the ratio of the slant range to the towfish altitude is computed for each time index and the 2 mean curves (port and starboard) of intensity vs. normalized slant range are computed for each file. Each file is one minute in length. For Herring Cove this resulted in 230 curves, for St. Margaret's Bay 550 curves. The features we define for the curves are the peak amplitude and the length of the curve between the peak and when the curves falls below 0.5 of this peak value. The altitude of the towfish will affect the amplitude somewhat (simply because the absolute range depends somewhat on the altitude). There is time-varying gain applied to the signal before processing so that this effect is somewhat mitigated, but ideally for seabed classification purposes one would like to keep the altitude of the towfish fairly constant during a survey.

Herring Cove

We start by showing in Fig. 14a the 230 curves from Herring Cove. It is clear that the maximum peak usually occurs at about the same value of normalized slant range (about 2) and that there is large variation in the peak amplitude. There is quite a clustering of amplitudes below about 100 and a wide variety of values above this. In fact, we will clip the value of

feature 1, the maximum amplitude of the across-track signal, at the value of 125. This is done so that past a certain threshhold (here, 125) the variation of amplitude is not considered important (i.e., the signal is classed as having a high return). In the clustering algorithm we wished to emphasize the variation of the second feature. In Fig. 14b the result of normalizing each curve by its maximum value is shown – as can be seen, this has significantly reduced the amount of variation within the plot. In Fig. 15 the mean curve computed from these normalized curves is shown. In Figure 16 the determined classes from the 2 features are shown. The classes determined by the clustering algorithm seem reasonable. The resulting geographical segmentation is shown in Fig. 17 – the results are contiguous areas of different classes, which agree nicely with the 120 kHz segmentation of Fig. 7b.

St. Margaret's Bay

We now repeat much of the analysis for St. Margaret's Bay. One important difference is that much of the sidescan data in St. Margaret's Bay had surface reflection data coming in at cross-ranges of 50m (or even less in some cases) for shallow water. This should not often affect feature 1 which is the peak amplitude, (however, we restrict the range of the search for the maximum, in order that maxima due to surface returns be windowed out) but it does affect feature 2 which is a measure of the distance from the peak to fall below 50% of the peak value. We compute the second feature but will only segment feature space on the basis of the peak amplitude. In Figure 18 we show the amplitude/cross-track curves and the normalized version. In this case the unnormalized curves are distributed fairly uniformly in peak amplitudes to 512. There are several peculiar curves in the normalized set – there are 2 main reasons for this. The presence of surface energy entering into the record at longer ranges means that some curves have significant energy arriving at the further ranges. Second, for the areas of very low return – LaHave clay – the altimeter on the towfish was often unable to detect a return – this means that the recorded altitude in the sonar record may be very inaccurate for these cases (and hence also the amplitude/normalized slant range curves). In Fig. 19 the mean curve is shown. This curve is very similar to that for Herring Cove, the only noticeable difference being the leveling off of the curve at the far ranges, which we attribute to the presence of surface noise in many of the sonar records. In Figure 20, the clusters resulting from the segmentation of the peak value are shown and the resulting geographical segmentation in Figure 21. This segmentation is, in general, consistent with the 120-kHz segmentation of Figure 13.

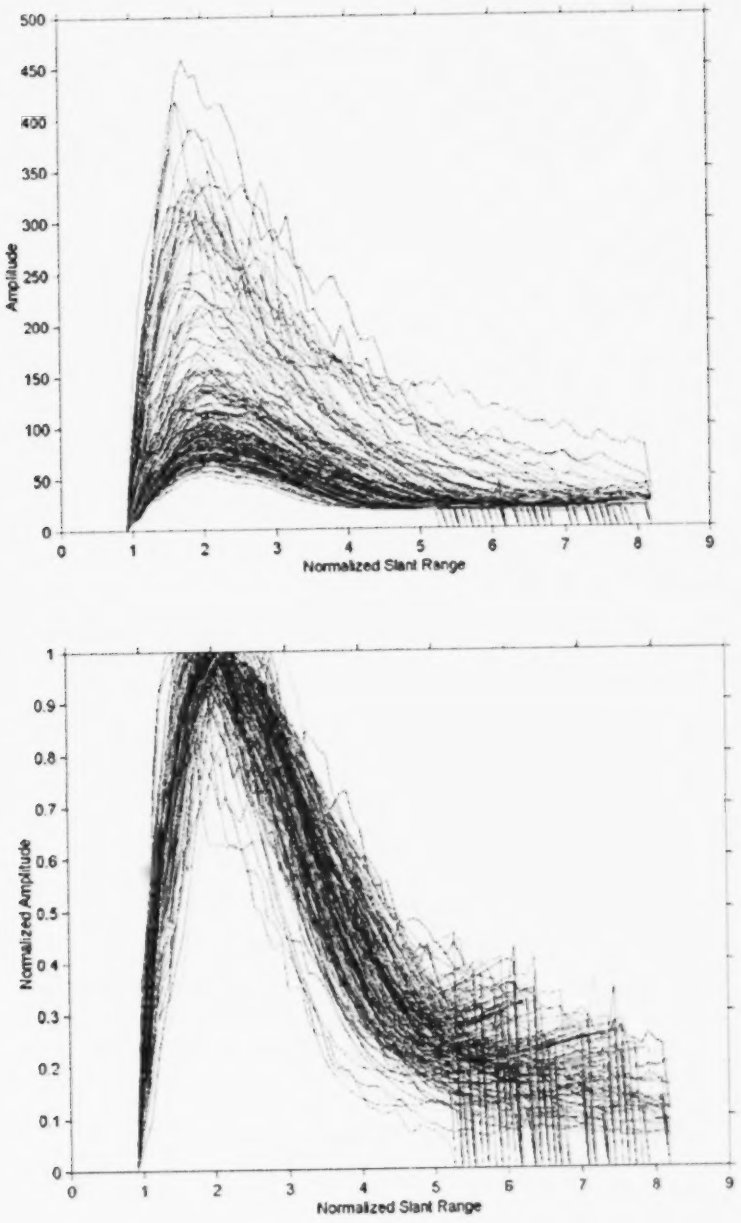


Figure 14 Amplitude/cross-range curves for Herring Cove and curves normalized to unit maximum amplitude.

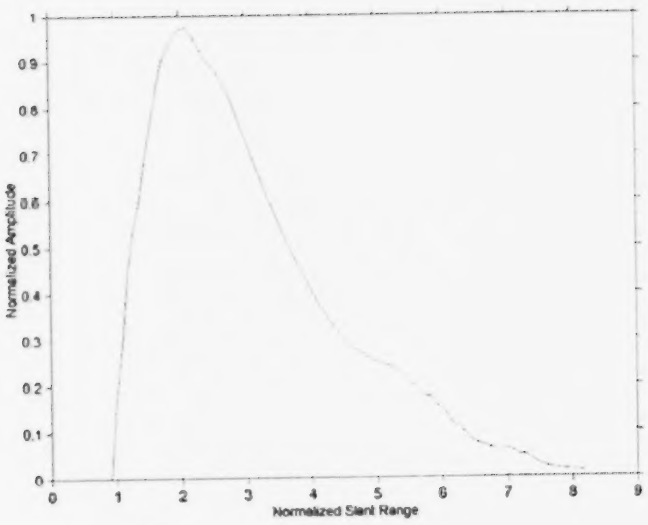


Figure 15 Mean Normalization curve for Herring Cove.

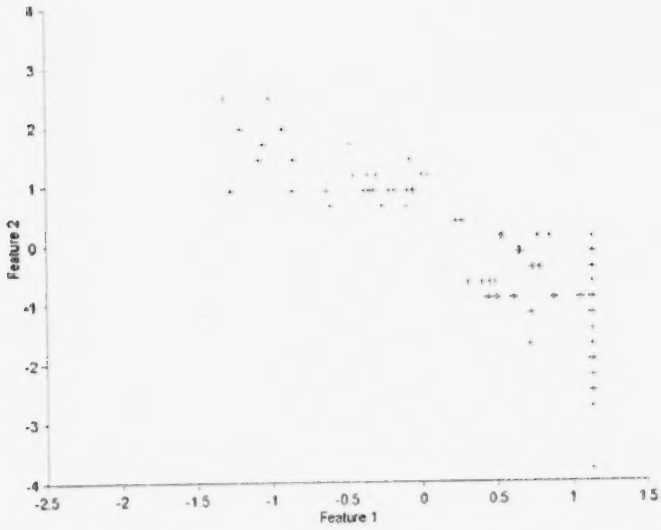


Figure 16 Cluster plot for features from Klein amplitude/cross-track range curves.

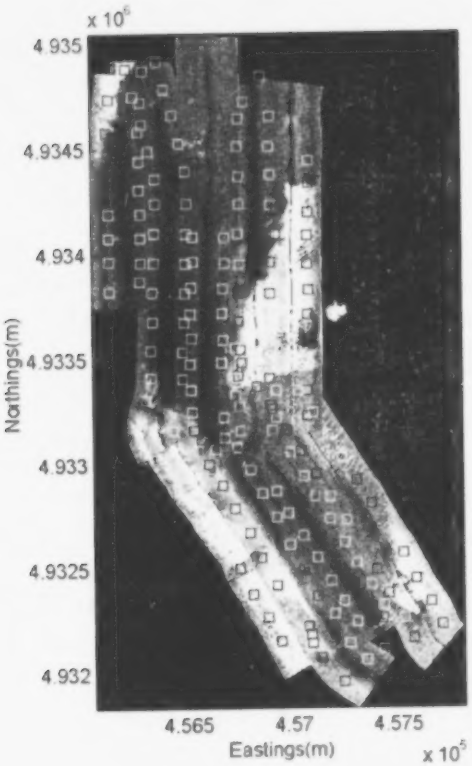


Figure 17 Geographical segmentations from Klein features for Herring Cove – the squares have been approximately placed by taking the midpoint of each file and displacing the squares 75m to the starboard and port of the position with respect to the mean heading of the towfish during the time of the file.

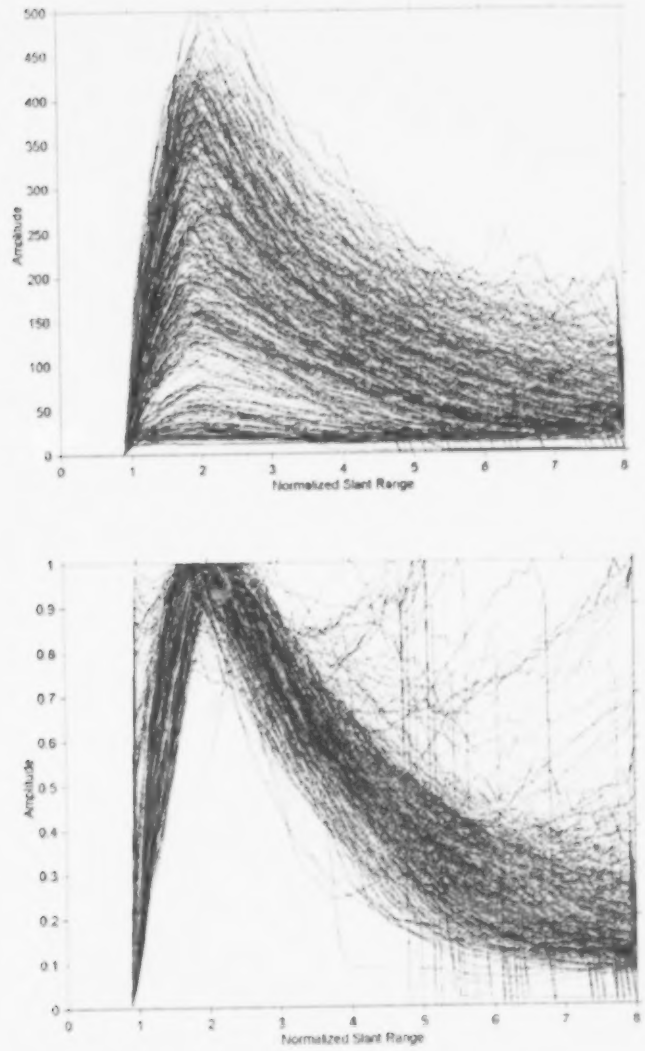


Figure 18 Amplitude/cross-range curves for St. Margaret's Bay – unnormalized and normalized.

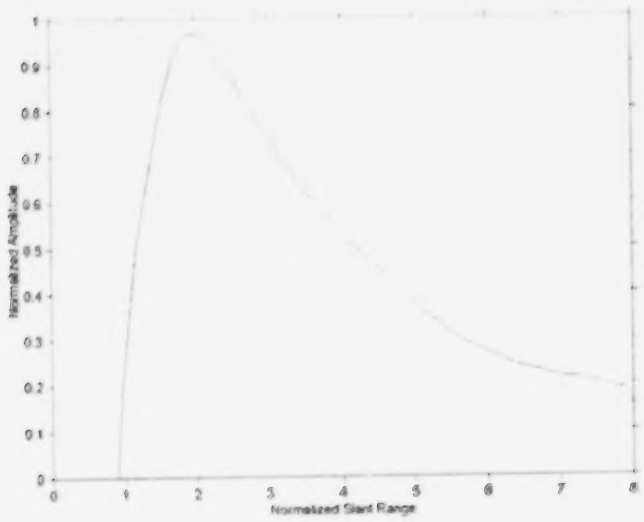


Figure 19 Mean normalization curve for St. Margaret's Bay.

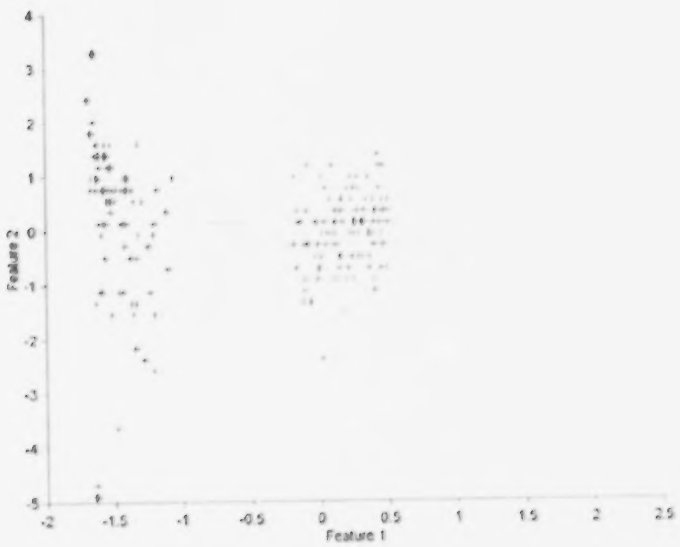


Figure 20 Segmented feature space for St. Margaret's Bay.

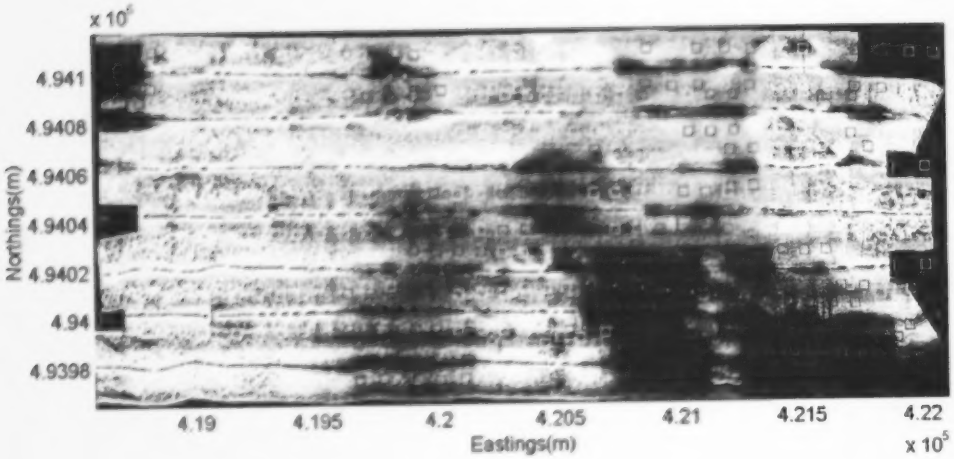


Figure 21 Geographical segmentation from sidescan data.

Summary

We have examined in this report the use of echo sounder and sidescan sonar returns to characterize the seabed. For the echosounder data we defined very simple features which we chose to basically reflect our visual characterization of the echo record. The results were encouraging in a number of aspects: (1) the geographical segmentations produced by all types of sensor seemed to be fairly contiguous – that is, there were significantly large regions with the same class, (2) when there were overlapping tracks the classifications usually agreed or were from a "neighbouring" class , (3) although there were differences between the results of using different frequencies (as one would expect) there were also similarities, (4) the results of segmenting the amplitude information for the Klein 5500 sidescan sonar yielded segmentations which were consistent with those from the 120-kHz sounder and (5) the segmentations and the character of the echos were consistent with the photographs. In the report we briefly discussed the different mechanisms of scattering: surface scattering and volumetric scattering and that as a result there is a frequency-dependence to the scattering. There are different seabed types which (particularly, at a single frequency) would give a statistically similar response. Thus, the unique interpretation of an acoustic region in terms of distinct seabed type (for example, silty/sand with biological activity) is difficult. Of course, if one has additional information such as photos, grab sample, etc., then it is possible to interpret the acoustic classification in terms of actual seabed types. Certainly, our analysis could determine areas of very low return corresponding to muddier/siltier conditions (particularly the LaHave clay) and firmer sediments, higher, compact return, and rocky areas.

In the future, we would certainly like to collect more of this type of data. The optimal fusion of information from different sensors (and frequencies) is an important area of research, as it may be that through the combination of this information, that the interpretation of acoustic classes in terms of actual seabed type can be made much more accurately and uniquely.

There are important reasons in Minecountermeasures for wishing to characterize the seabed. One reason is the prediction of areas of possible mine burial. Second, is the characterization of areas where mine detection by sonar would be difficult. This could be areas of clutter where it would be difficult to distinguish minelike objects from the surrounding natural objects and areas of mud and silt where the sonar return is low and a target shadow/background contrast on a sidescan sonar image would be expected to be poor.

Acknowledgements

I would like to thank Dr. Mark Trevorrow for informative discussions on the details of the echosounder data sets. Dr. Anna Crawford provided the sidescan sonar mosaics for Herring Cove and St. Margaret's Bay. Vincent Myers wrote a MATLAB program to read the echosounder data files. I would also like to thank Dr. Eric Pouliquen of SACLANT Centre for interesting discussions and exchange of results. The photographs shown in this report were collected by RV Alliance of SACLANTCEN.

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Appendix A – Some sidescan images and photographs

Herring Cove

In this portion of the Appendix we show "screen-grabs" from the Klein sonar display program for 7 areas of the survey of Herring Cove; in particular, north of Litchfield shoal (approx Pt.2 on the mosaic of Fig. 3), just starting over the shoal, over the shoal, off the shoal into the area of striations, near point 8 on the mosaic, near point 9, and finally along the shoreline, just south of point 12. The first image shows a very uniform seabed, the second shows the very distinct boundaries between the shoal material and the background as the shoal is approached, the third image shows that while the shoal has exposed rock there are also sections of different sediment cover including ripples (which are somewhat difficult to see at this reduced size). The fourth image is just after the shoal showing an area of interesting streaking. The next image is further along in the survey; the background is again fairly uniform and two cylinders that were placed on the bottom for mine detection studies can be seen. The next image is taken as the shoreline is approached and there is an area of higher reflectivity. This does not correspond to boulders, as can be seen closer to the shore, but to some higher reflective material. The final image is further up the shoreline where definite ripples can be observed. The next 3 screen grabs are from the southern survey – one along the shoreline and two from the central portion of the run. It is important to note that the display software for the Klein data performs a moving equalization to the data, so that it is not possible to infer the absolute levels (or even the relative absolute levels) of the displays in Figs. 22-26.

Following the sidescan sonar images, some selected underwater photographs collected by R.V. Alliance are shown. They correspond to the positions indicated in yellow in Fig. 3. Four of the photographs indicate a fairly soft bottom with biologics, such as starfish or burrow holes. There is also a photograph showing a seabed with fine gravel. Finally, the photograph taken from a site over Litchfield Shoal indicates the rough, rocky bottom in this area.

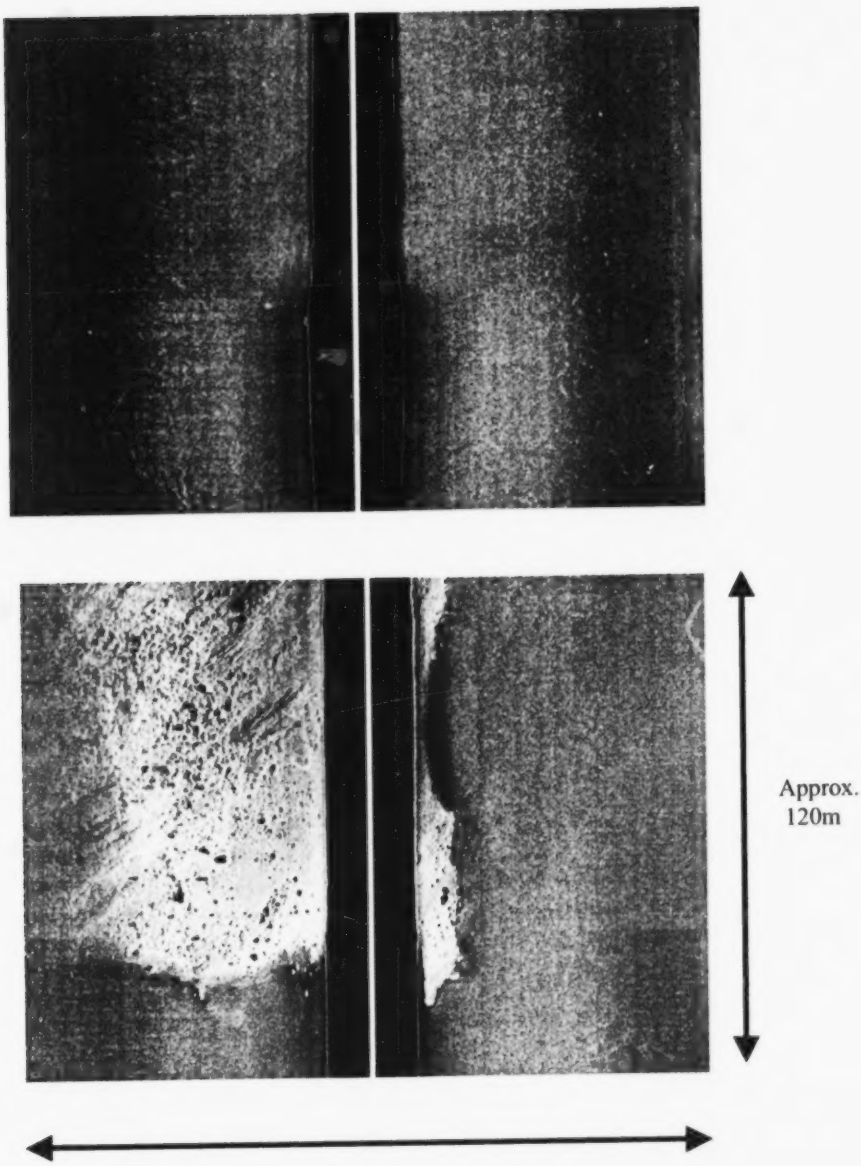


Figure 22 Sidescan screen grabs - (top) north of Litchfield Shoal (bottom) coming over the shoal.

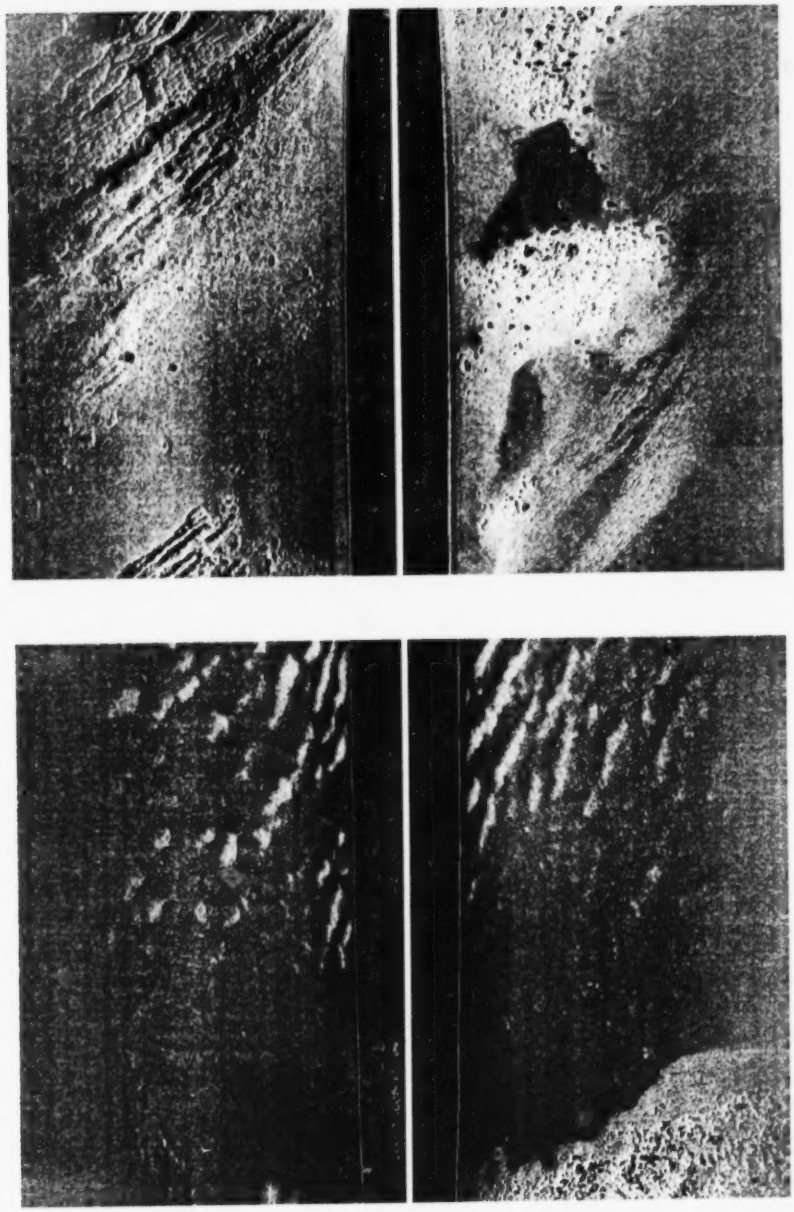


Figure 23 Sidescan screen grabs - (top) over the shoal (note the variations) (bottom) coming off the shoal - note the striations.

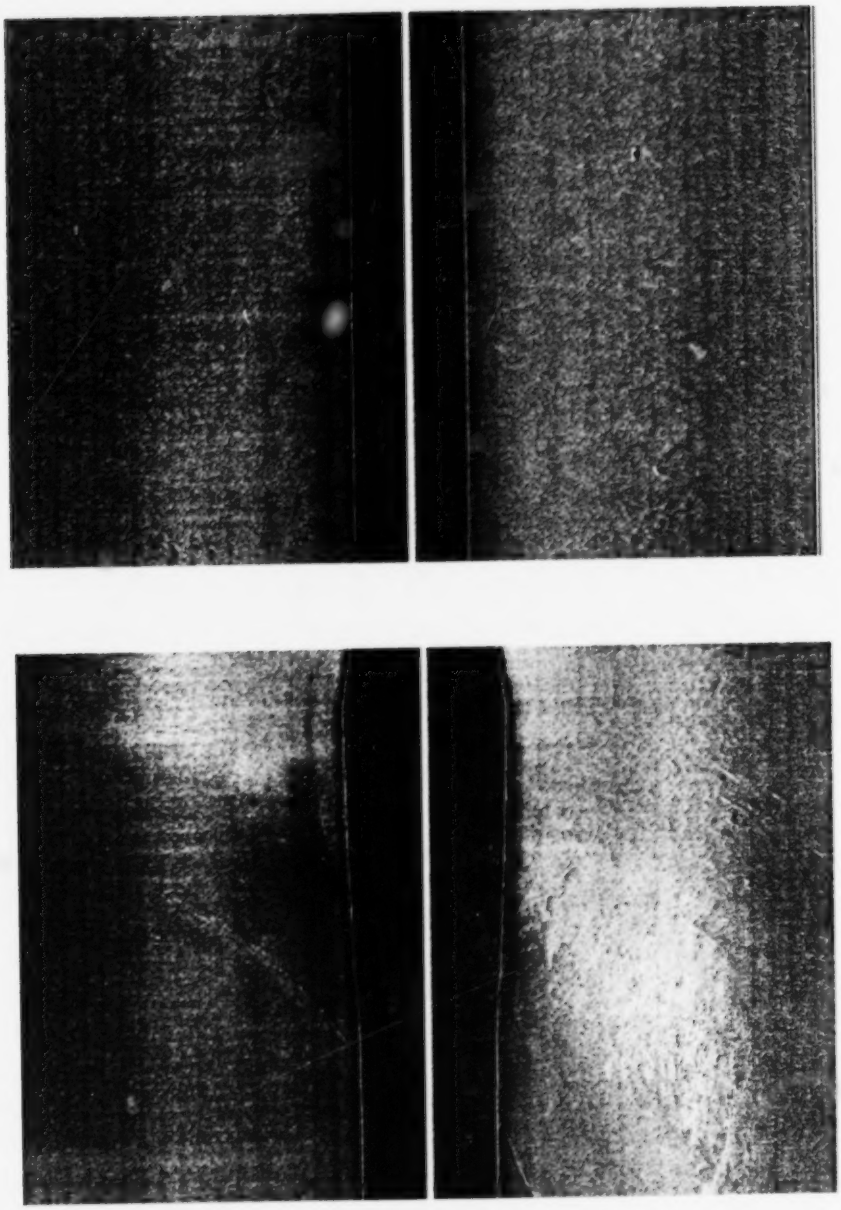


Figure 24 - Near points 8 (top) and 9 (bottom) on the mosaic, note two of the cylinders that were placed on the seabed.

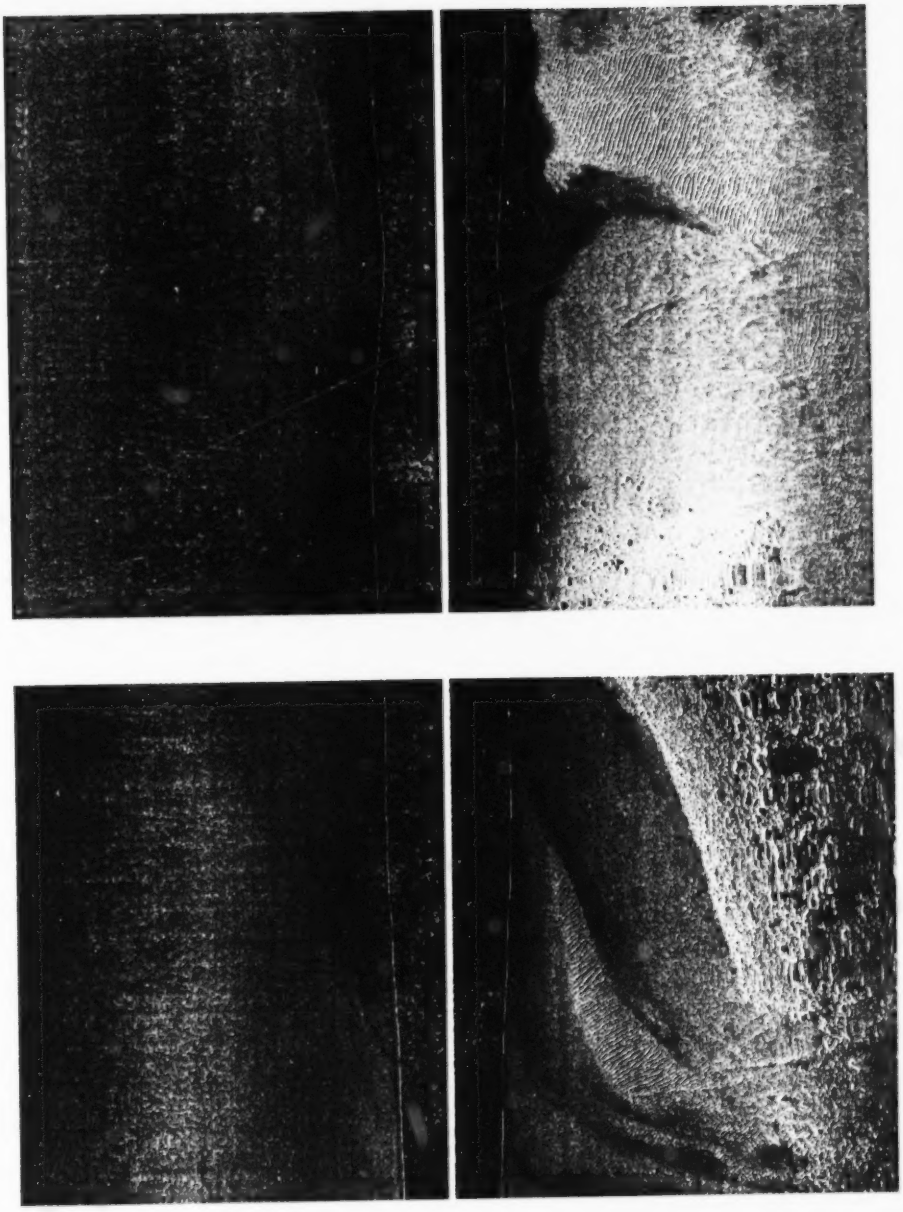


Figure 25 Along the shoreline - near point 12 from Run 1 and point 0 on Run 2.

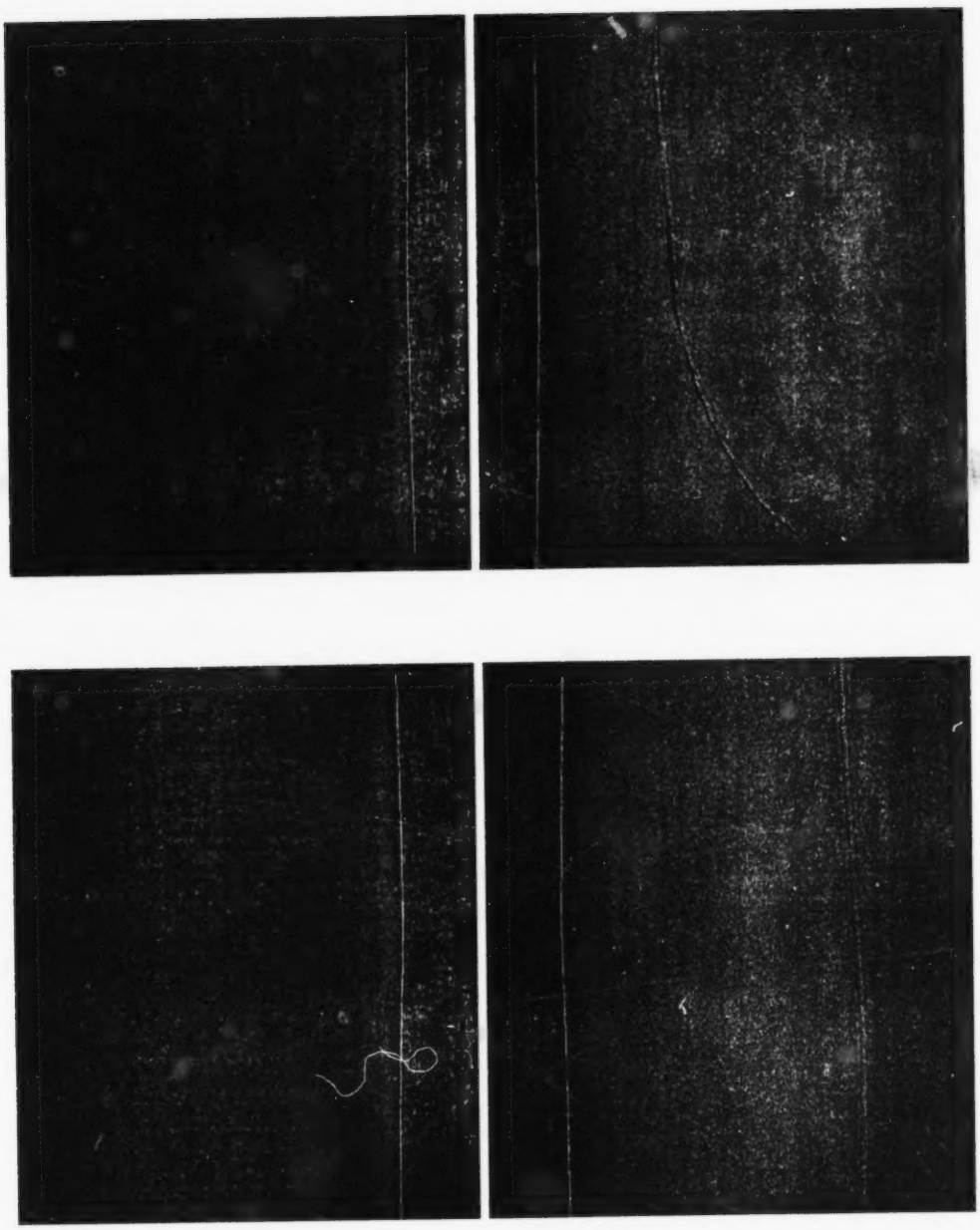


Figure 26 Along the middle part of the southern run – near point 5 and halfway between point 5 and 6 – note the cable on the starboard side.

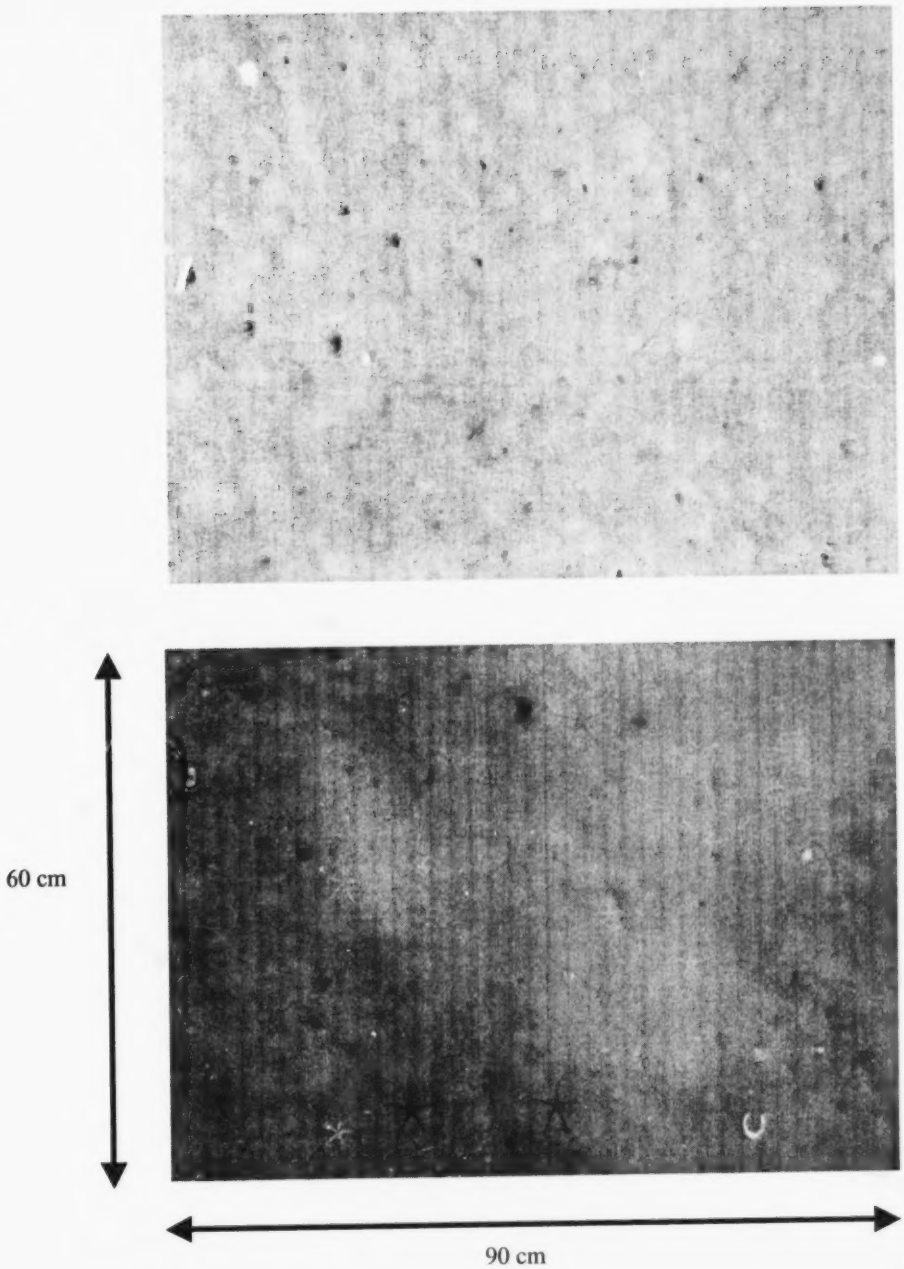


Figure 27 SACLANT photos (indicated by 1 and 2 in Fig. 3) of the bottom – note the starfish in the second photo and the evidence of bioturbation in the bottom.

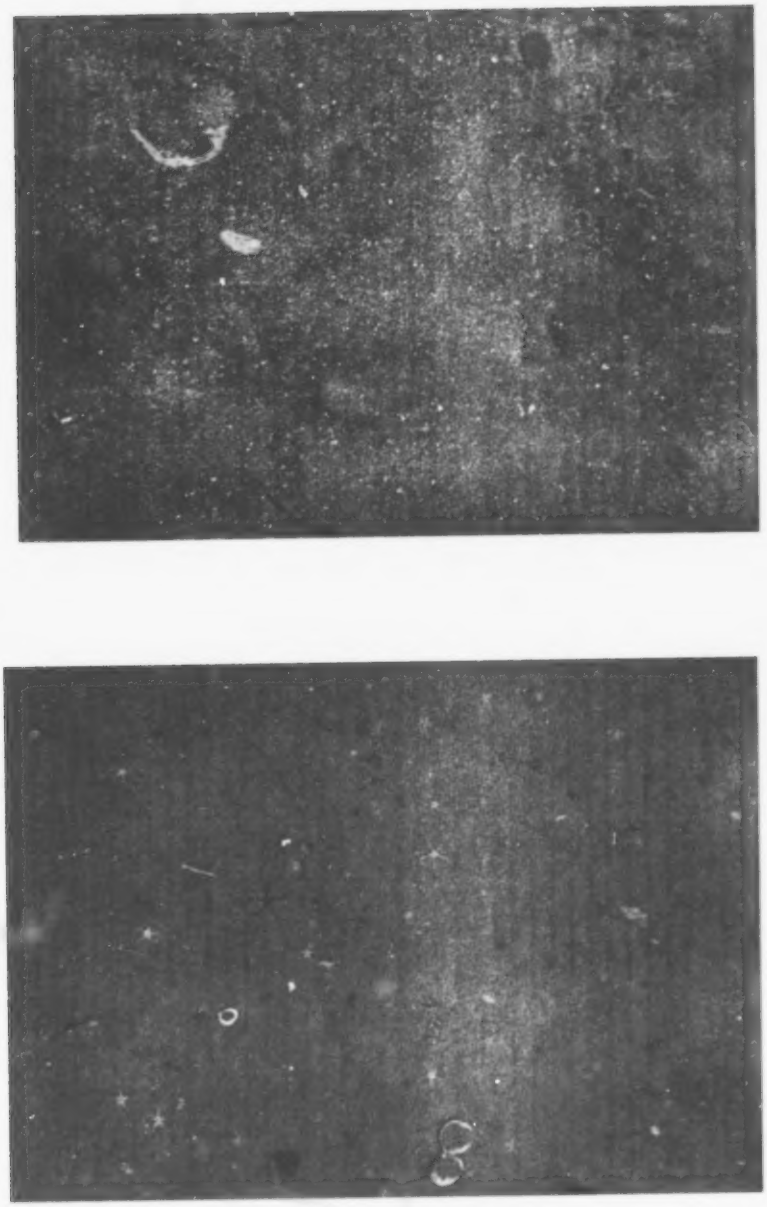
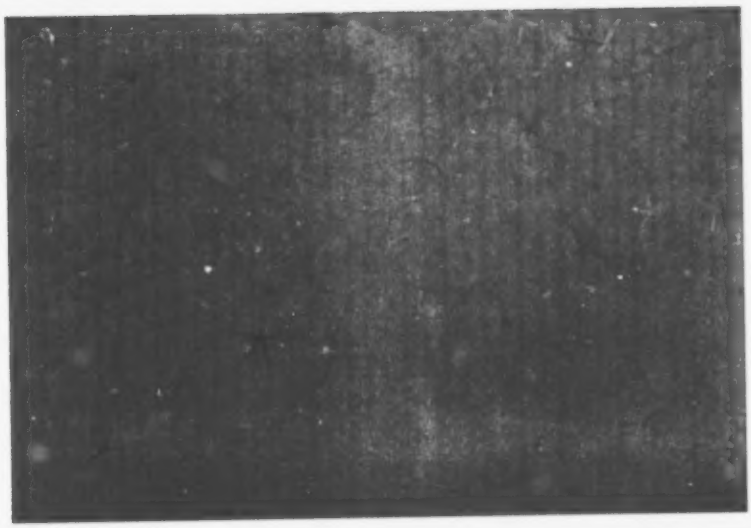


Figure 28 - Photos 3 and 4 from Herring Cove – the top photo shows more of a gravelly seabed whereas photo 4 is similar to photo 2.



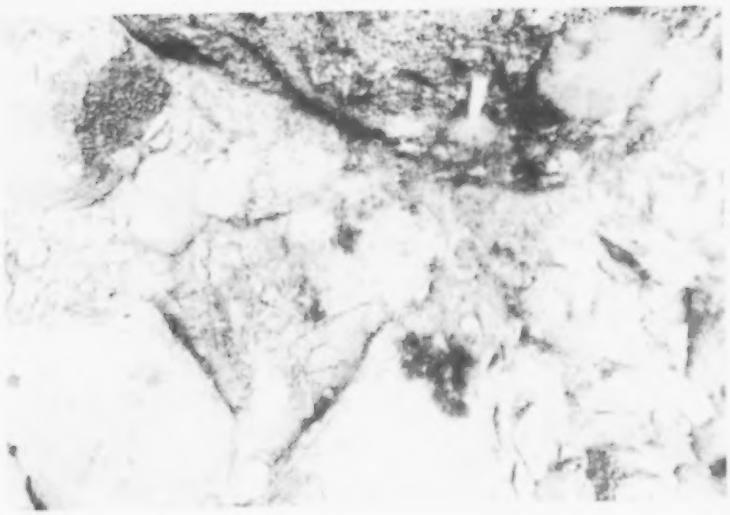


Figure 29 – Photos 5 and 6 from Herring Cove – the bottom one is on Litchfield Shoal and the rock is evident as well as sea anemones.

St. Margaret's Bay

Below, we present a number of screen grabs from the Klein 5500 sidescan sonar from different locations in the survey of St. Margaret's Bay. Following these, a number of representative underwater photographs are presented. The positions of these sidescan images and photographs are indicated on Fig. 10.

The sidescan images and the photographs indicate the wide variety of seabed conditions that were present in the survey area. On the sidescan images there are regions of relatively homogeneous background (perhaps sand), there are images with "dark patches" on the background (possibly vegetation). There are regions where boulders or boulder fields are present. In some images of the survey, ridges of boulders can be observed.

The photographs indicate the large amount of variation in the details of the seabed. There are areas of significant amounts of algae, areas where the bottom appears to contain more shell or gravel, areas of muddy clay and starfish, etc. It is difficult to know exactly how these various details will manifest themselves in the echosounder and sidescan sonar imagery. The acoustic response of the seabed is, in fact, a combined response of all the different surface and volumetric scatterers.

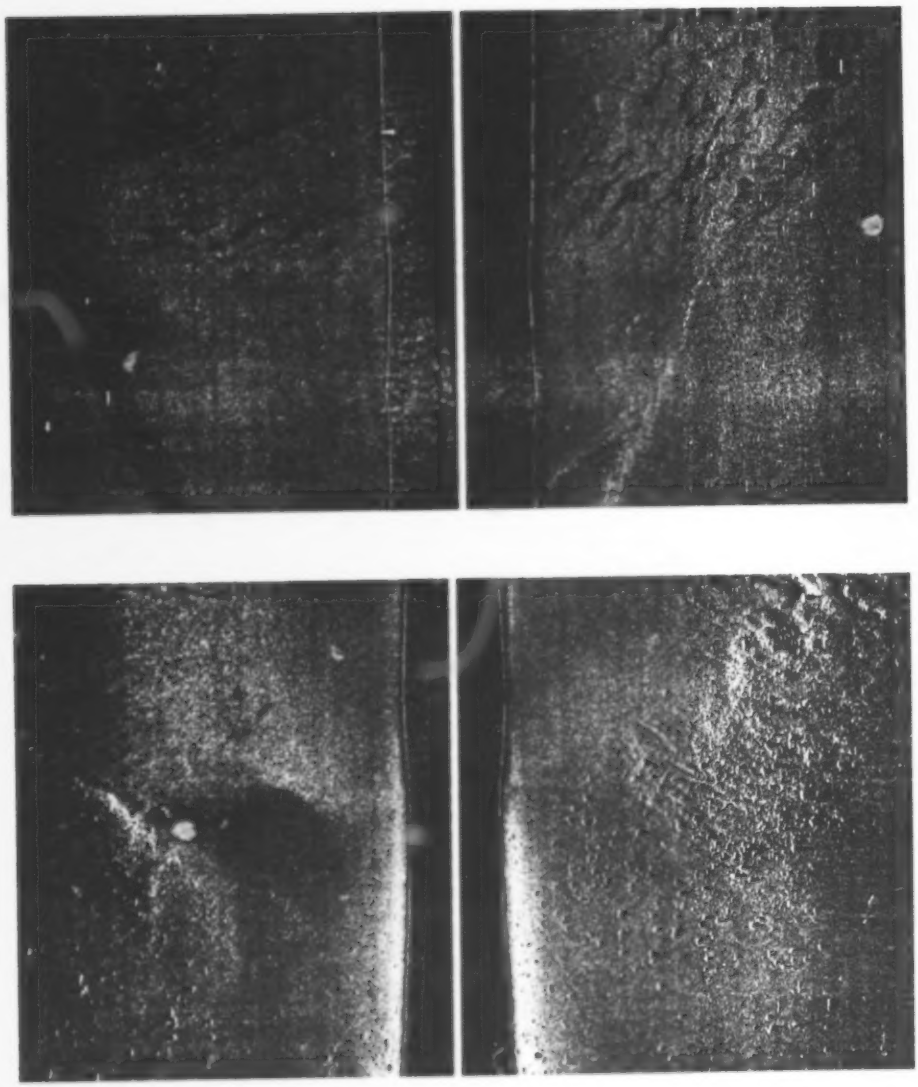


Figure 30 Screen grabs from Klein 5500 display – (top) position 1 and (bottom) position 2 on mosaic of St. Margaret's Bay – note the patchiness in the top figure and the boulders in the bottom figure.

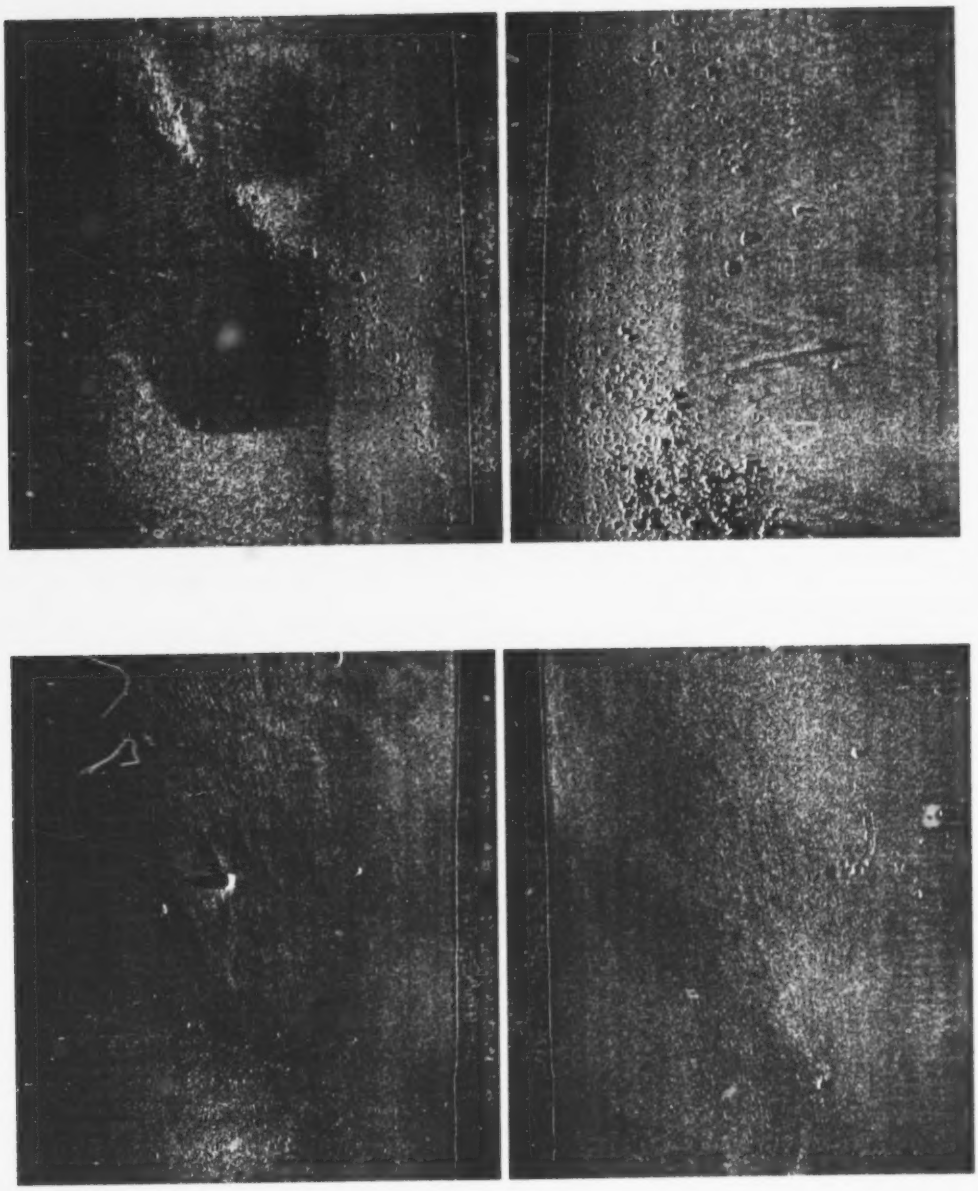


Figure 31 Sidescan sonar images from positions 3 and 4 – note the boulders and the ridge of boulders in the top image.

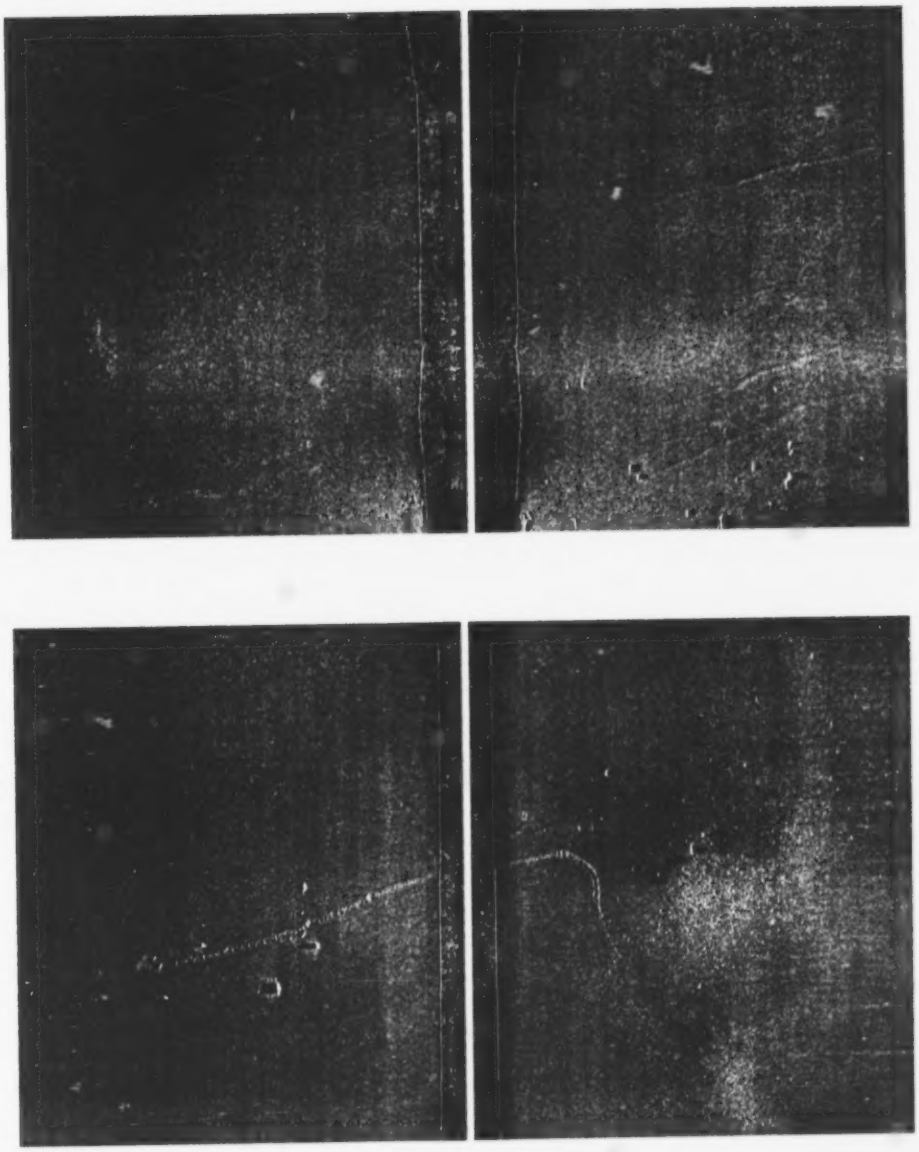


Figure 32 St. Margaret's Bay sidescan images 5 and 6 – a scour mark is noticeable in the bottom image.

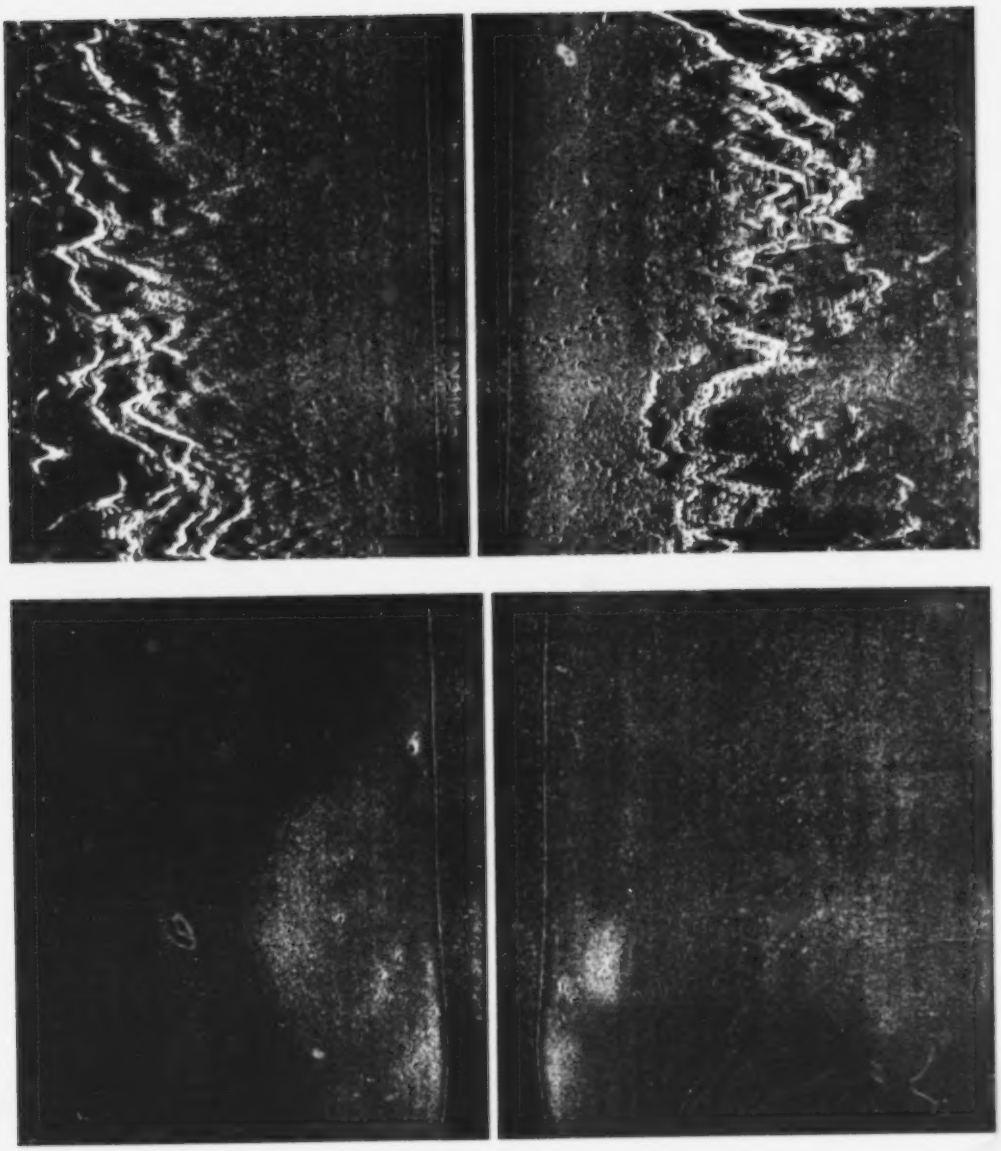


Figure 33 Sidescan images 7 and 8 – image 7 is from a shallow site and the surface return can be seen from about the 75m range onwards.

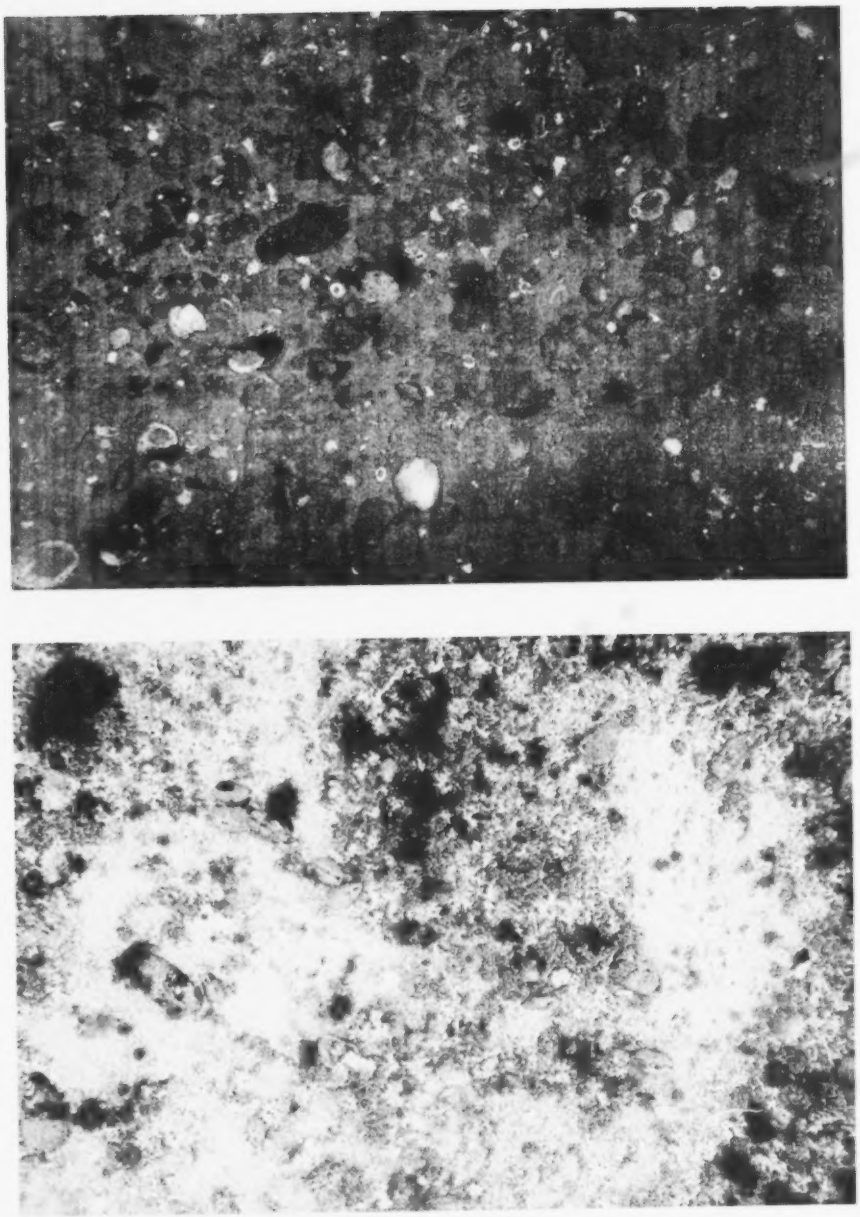


Figure 34 - Photos 1 and 2 for St. Margaret's Bay – note the cluttered bottom and the biology – the second image seems to have a more "shelly" bottom.

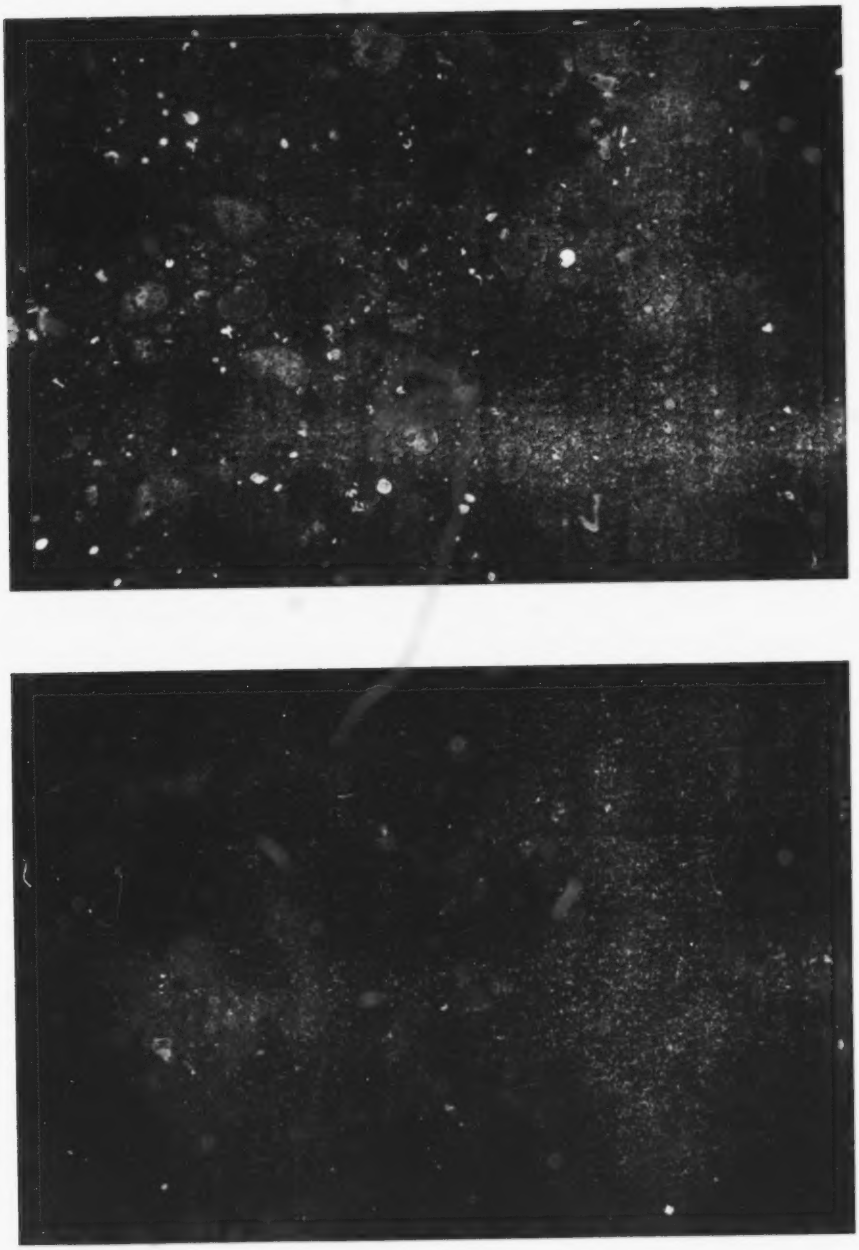


Figure 35 – Photos 3 and 4 – these 2 images are similar with purple rocks and vegetation.

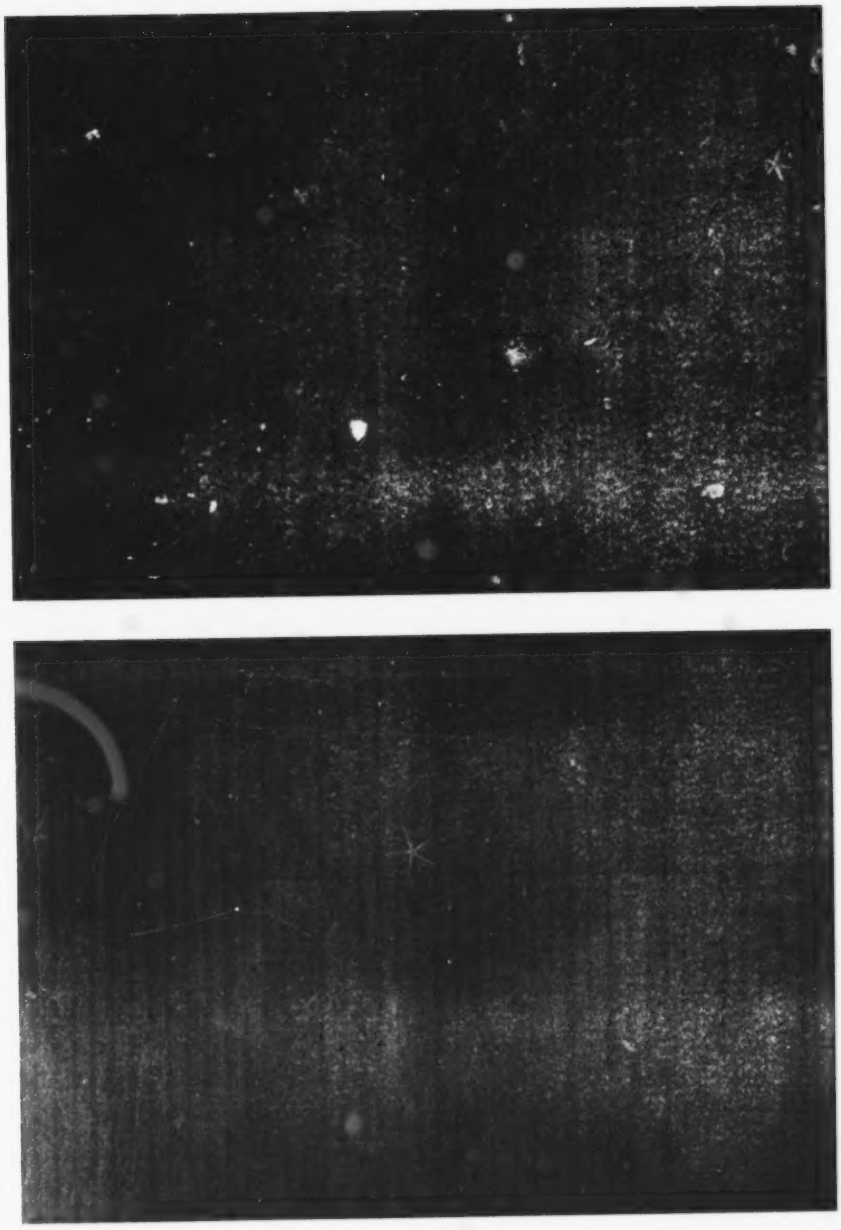


Figure 36 – Photos 5 and 6 – although it is dark, photo 6 seems to show a muddier bottom, a star fish can be seen near the centre.

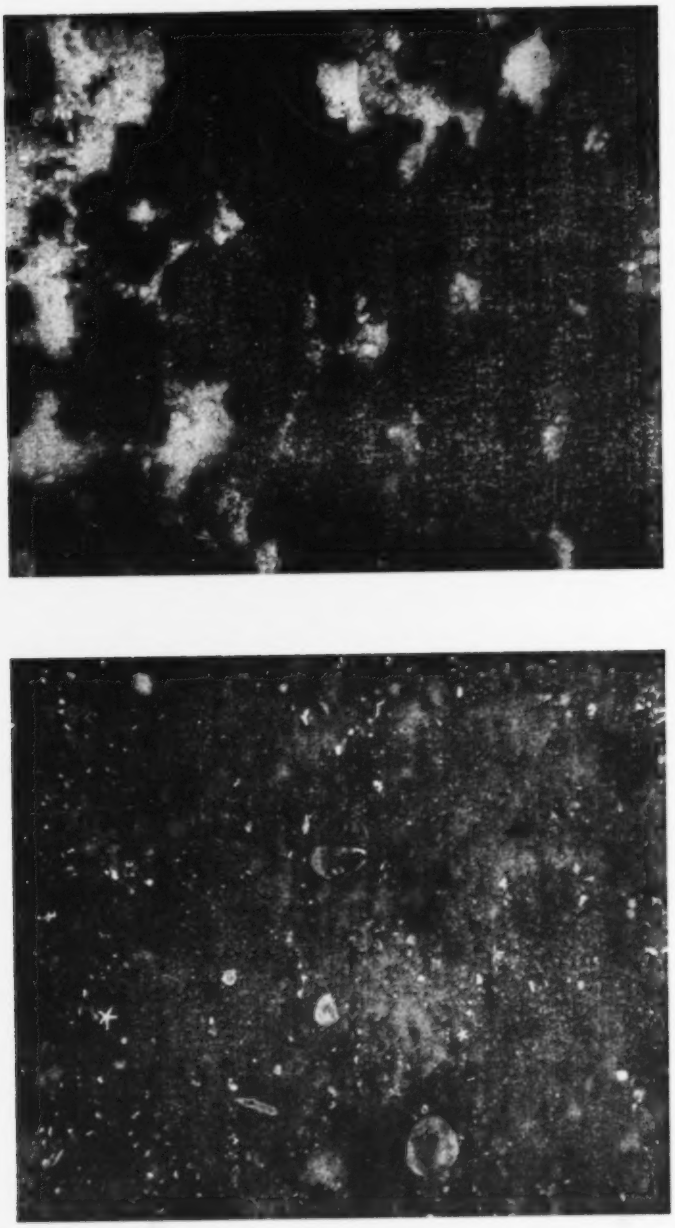


Figure 37 – Photos 7 and 8 – Photo 7 shows a significant amount of vegetation.

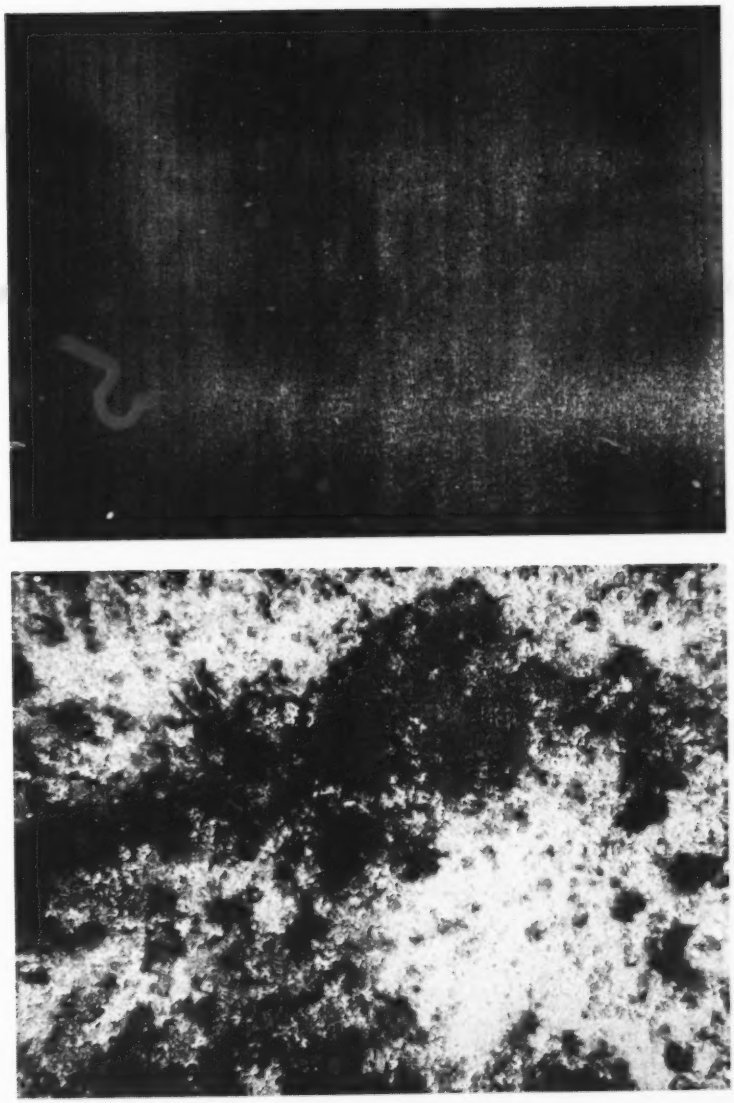


Figure 38 – Photos 9 and 10.

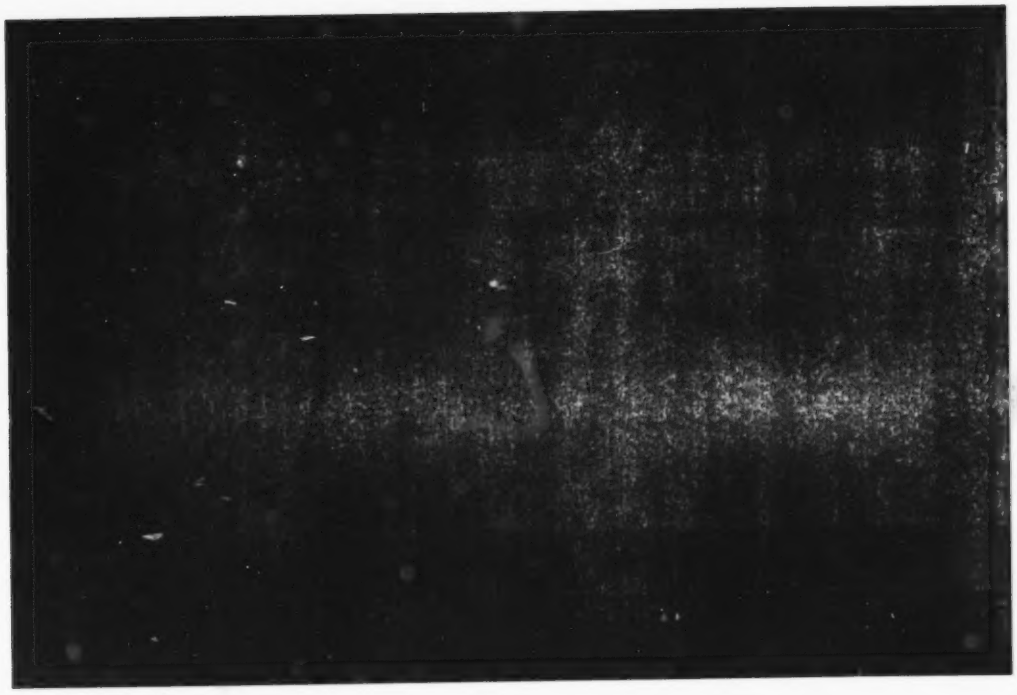


Figure 39 – Photo 11 from St. Margaret's Bay.

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The properties of the seabed affect the amplitude and character of an echosounder or sidescan sonar return. Conversely, it is possible to use the statistical variation of these returns to segment the seabed into various regions – according to their acoustic characteristics. In this report we consider the returns from the SIMRAD echosounder (two different frequencies) on the CFAV Quest as well as the returns from the Klein 5500 sidescan sonar collected during the DRDC-Atlantic/SACLANTCEN trial, MAPLE.. Acoustic features are defined which allow us to segment the seabed into different acoustic regions for two different sites, Herring Cove, Halifax Harbour and St. Margaret's Bay. As well, some selected underwater photographs taken by SACLANTCEN and selected sidescan sonar images are presented from the 2 sites.

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seabed classification, echo sounder, sidescan sonar

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